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NOTICES.

The Institution as a body is not responsible for the statements of opinion expressed in any of its publications.

Copyright.—Publication of abstracts of Papers and articles appearing in the Journal is permitted, provided that acknowledgment is made to the Institution of Petroleum Technologists.

Papers and Articles.—The Council invites Papers and Articles both for reading at Ordinary Meetings of the Institution and for publication in the Journal. All Papers, whether for reading or publication, will be submitted to a referee appointed by the Publication Committee.

The Institution has published a brochure "Instructions for the Guidance of Authors" containing details of recommended practice in the preparation of Papers for publication. Copies of this brochure will be supplied on request.

Pre-Prints.—Advance proofs of Papers to be read at Ordinary Meetings are generally available about a week before the Meeting. Members wishing to be supplied with these pre-prints are requested to notify the Secretary.

Abstracts.—Members and Journal Subscribers desirous of receiving the Abstracts printed on one side of the paper only, can be supplied with these at a charge of 10*s.* per annum per copy, payable in advance.

Issue of Journal.—Members whose subscription is not in arrear receive the Journal free of cost. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

Changes of Address.—Members are requested to notify any change of address to the Secretary.

Benevolent Fund.—The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

Appointments Register.—A register of members requiring appointments is kept at the offices of the Institution, and every effort is made to assist members of the Institution in search of employment.

Members who desire their names and qualifications to be included in this register are requested to apply to the Secretary for the Form of Application for Registration, if they have not already done so. Members residing in the London area are asked, if possible, to return this Form in person and make themselves known, together with their requirements, to the Secretary. It is also requested that members should notify the Secretary immediately they have obtained an appointment.

In submitting names of candidates to prospective employers it is understood that the Institution accepts no responsibility and gives no guarantee.

Library.—The Institution's Library may be consulted between the hours of 9.30 a.m. and 5 p.m. daily. (Saturdays, 9.30 a.m. to 12 noon.)

NOMINATIONS FOR MEMBERSHIP.

The following nominations for membership of the Institution of Petroleum Technologists were approved by the Council on 12th November, 1935, and the application forms may be seen at the offices of the Institution.

The names of the Proposer and Seconder are given in parentheses.

As Member.

FAY, Eric, Refinery Superintendent, Caribbean Petroleum Co., Maracaibo, Venezuela. (G. O. Higgins; G. S. Taitt.)

As Transfer to Member.

OWEN, Robert Meyer Sturt, Geologist, 102, Administration Building, Edmonton, Alberta. (W. Calder; L. Owen.)

As Associate Members.

BURGESS, Stanley Grove, Chemist, 26, Eastbourne Gardens, East Sheen, S.W. 14. (R. Lessing; J. Kewley.)

HOWGILL, Donald Robert, Mechanical Engineer, c/o Asiatic Petroleum Co. (S.S.), Ltd., Singapore. (L. H. Cooper; A. D. Cooper.)

LOW, Ian Campbell, Engineer, Dowrich House, Sandford, nr. Crediton, Devon. (W. E. Gooday; R. G. Stickland.)

MARKS, Randolph Errol, Engineer, Fairhaven, Littleover, nr. Derby. (R. W. Stiles; W. E. Gooday.)

TIDY, Sydney George, Chemist, c/o Anglo-Iranian Oil Co., Ltd., Abadan, South Iran. (C. J. Wright; C. V. Rutherford.)

As Associates.

RANKIN, George, Chief Cost Accountant, c/o Anglo-Ecuadorian Oilfields, Ltd., Casilla 410, Guayaquil, Ecuador. (C. B. Brown; G. H. S. Bushnell.)

SOPER, William Ewart, Lubricating Manager, Socony Vacuum Oil Co., P.O. Box 660, Istanbul, Turkey. (S. J. M. Auld; N. G. Gullick.)

WYKES, Frederick Edgar, Merchant Naval Officer, 65, Spa Road, Weymouth, Dorset. (H. Keith; F. N. Harrap.)

APPLICATION FORMS FOR ADMISSION.

The Council desire to direct the attention of members who Propose or Second an Application Form for admission to the Institution to the importance of sending a covering letter for the guidance of the Election Committee.

NOMINATIONS FOR COUNCIL.

Members are reminded that in accordance with the By-Laws, Nominations for Council must be in the Secretary's hands not later than 30th November next. Nomination Forms may be obtained from the Secretary.

ASSOCIATED STUDENTS.

In order to enable junior employees of petroleum companies to participate in the activities of the Students' Section of the Institution, the Council has approved "Associated Students" of this Section.

Associated Students will be entitled to receive notices of and to attend meetings of the Students' Section, and to make use of the Institution Library. They will not receive the *Journal*, and will not be eligible for Students' Prizes.

The subscription of an Associated Student is 7*s*. 6*d*. per annum, which should be paid to the Honorary Secretary, Students' Section (London Branch), Mr. B. C. Ferguson, St. Helens Court, Great St. Helens, London, E.C. 3.

There is at present no age limit for Associated Students, but they will be required to proceed to Student or other grade of Membership (according to age) before the expiry of two years from the date of their becoming Associated Students.

COUNCIL BUSINESS.

The Council has authorized the publication in the "Institution Notices" of a short account of important matters under consideration at Council Meetings.

Method of Election of Members.

The Council has instructed the Election Committee to examine and report upon the efficacy of the present method of election of members by ballot. The number of Ballot Lists returned each month, having regard to the number issued, is comparatively small. The Committee will investigate whether a change in the present procedure would be advisable.

Monthly Institution Meetings.

During the second half of the 1935–36 Session the Council has decided to experiment with two meetings of a character somewhat different from that of the usual monthly Paper. In February and April 1936 two meetings are being arranged devoted to "*Welding in the Petroleum Industry*" and "*Carbonization as a Source of Liquid Fuels*," respectively. At each meeting several Papers will be briefly presented by their authors. Following an interval for refreshments, discussion of the Papers will be resumed at about 7.30 p.m. and will continue until 9 p.m.

The whole question of the most suitable form of monthly meeting is being given careful consideration by the Council and the Publication Committee. On the one hand, increasing specialization of petroleum technology renders the selection of subjects of wide appeal more and more difficult. On the other hand, the Council wishes to avoid the danger of arranging meetings of a "popular" type only. The suggestions for symposia referred to above are an experiment in the direction of determining the most suitable type of meeting, designed to allow the fullest opportunity for the exchange of experiences and ideas.

ARTHUR W. EASTLAKE.
Honorary Secretary.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary for insertion under this heading.

Mr. W. L. Bouch has left for Iran.

Mr. R. Broadhurst is home from Sarawak.

Mr. R. Fallah is in Iran.

Mr. C. J. Johnson has returned to Iran.

Mr. R. B. Kerr is home from Trinidad.

Mr. Percy Meyer has left for Aruba.

Mr. D. G. Pidgeon has returned to Iran.

The Secretary would be glad to learn of the addresses of the following members: A. MacLean, I. G. Nixon, W. W. Pearce and K. A. Spearing.

BRANCH NOTES.

Students' Section (London Branch).

A stimulating survey of the "Value of Research in the Petroleum Industry" was given by Dr. A. E. Dunstan at the opening meeting of the Students' Section (London Branch) on Monday, 14th October. Beginning with the treatment of shale oil by James Young in 1847, Dr. Dunstan traced the development of various refining processes down to the recent methods of treating lubricating oil distillates with preferential solvents. The underlying chemistry of adsorption phenomena, treatment with liquid SO_2, desulphurization with alkaline hypochlorites, and hydrogenation reactions was discussed. Throughout his address Dr. Dunstan laid stress on the interdependence of empirical methods and scientific research. More often than not, the research worker was called upon to explain processes developed by empiricism, the results of his research yielding valuable pointers to future progress.

The following Student Members took part in the discussion: R. H. Keach, W. R. Wright, H. T. Lorne, G. M. Barrett, B. O. Lisle, A. J. Haworth and H. E. W. Kirby.

* * * *

Mr. A. S. Bridgwater, Chairman of the Students' Section (London Branch), announced at the above meeting that a Prize had been offered to the Section for the Student or Associated Student whose contributions to the discussions throughout the Session were considered most meritorious by the Committee of the Branch. Members of the Committee would not themselves be eligible for this Prize.

* * * *

A new feature is being introduced in the programme of meetings of the Students' Section for the present Session by the inclusion of a series of special lectures on the political and economic geography of various oil-

producing countries. The purpose of these lectures is to present to students likely to proceed abroad a preliminary survey of conditions prevailing in various countries. The lectures will prove of equal interest and value to the junior members of the London staffs of companies operating overseas.

The first lecture is to be given on December 17th by Dr. Dudley Stamp (Sir Ernest Cassel Reader in Economic Geography at the London School of Economics), and will deal with Burma, India and the East Indies. On February 4th, 1936, Prof. Rodwell Jones (Professor of Geography at The University of London) will deal with Trinidad, Venezuela and Central America. A further lecture is being arranged to cover Iran, Iraq and Egypt.

* * * *

"The History and Development of Tankers" was the subject of an interesting and informative paper by Mr. B. Orchard Lisle on November 5th.

From the primitive Chinese junk of 1770, the author traced the development of the tanker to modern times. He illustrated the advances in design by an excellent series of lantern slides and of drawings and photographs. In conclusion reference was made to the importance of such matters as speed, cargo capacity, etc.

The following Student Members took part in the discussion: R. H. Keach, A. J. Haworth and R. I. Martin.

* * * *

Students' Section (Birmingham Branch).

The following constitute the Committee of the Students' Section (Birmingham Branch) for the Session 1935–36: Chairman: P. A. Taylor; Vice-Chairman: C. S. Newey; Members of Committee: J. H. Dove, A. Nissan, E. M. Holbrook; Hon. Secretary: L. V. W. Clark, B.Sc.

* * * *

Dr. Dudley Stamp and Prof. Rodwell Jones have kindly consented to repeat their lectures on the Political and Economic Geography of various oil-producing countries referred to above, before the Birmingham Branch of the Students' Section on January 23rd and February 13th respectively.

THE THIRD WORLD POWER CONFERENCE.

It is announced that the Third World Power Conference will be held in Washington, U.S.A., from September 7th to 12th, 1936. Invitations were issued on September 26th, 1935, by the State Department—United States Foreign Office—on behalf of President Roosevelt. The International Executive Council of the World Power Conference had already decided unanimously to accept such formal invitations when issued.

This will be the Third Plenary meeting of the World Power Conference, the First Plenary meetings having taken place at Wembley in 1924, and the Second at Berlin in 1930. There have in addition been a number of

Sectional meetings. The Chemical Engineering Congress of the World Power Conference, to be held in London next June, ranks as one of these series of Sectional meetings.

The general subject to be discussed at the Third World Power Conference is the National Power Economy. Among the aspects to be treated are the following: Physical and Statistical Bases; Technical, Economic and Social Trends; Organization of Fuel Industries and of Gas and Electric Utilities; Public Regulations; National and Regional Planning; Conservation of Fuel and Water Resources; Rationalization of Distribution; National Power and Fuel Policies.

The Second Congress of the International Commission on Large Dams of the World Power Conference will be held in Washington at the same time.

Further particulars regarding the Plenary meeting of the World Power Conference and the Second International Congress on Large Dams will be issued in due course. British participation will be organised by: British National Committee of the World Power Conference, 36, Kingsway, London, W.C. 2.

ENGINEERS' GERMAN CIRCLE.

Members of the Institution of Petroleum Technologists may be interested in the activities of the Engineers' German Circle which meets in London during the winter months. The Circle was formed in 1931, with the joint support of the Institution of Mechanical Engineers and the Verein deutscher Ingenieure, Berlin. The objects of the Circle are to further the study of technical German and to bring together engineers interested in Continental technical developments. In addition to lectures in German by eminent German-speaking engineers, opportunities are afforded for informal discussion in German both before and after the meetings. The lecturers are asked to use simple forms of expression and to speak rather more slowly and distinctly than they would in addressing their own countrymen, whilst the liberal use of lantern slides is also an aid to understanding. It has been the experience of many members of the Circle whose knowledge of German was at first elementary, that the lectures have been a valuable means of improving their knowledge of the spoken language.

The membership subscription is 7*s*. 6*d*. per annum. Further particulars and application forms for membership can be obtained from Mr. E. L. Diamond, M.Sc., The Institute of Mechanical Engineers, Storey's Gate, Westminster, London, S.W. 1.

BACK NUMBERS OF JOURNAL.

The Institution is desirous or purchasing a limited number of clean copies of Journal No. 19, April 1919.

The price which will be paid for such copies is 7*s*. 6*d*., and all enquiries should be sent to the Secretary.

OBITUARY.

N. W. Graham.

We regret to announce the death of Mr. Nelson Woodthorpe Graham in London on Tuesday, October 22nd, 1935.

At the time of his death Mr. Graham was Field Manager in Trinidad of Messrs. Trinidad Leaseholds, Ltd. He was elected a Member of the Institution of Petroleum Technologists in 1934.

Mr. Graham was born at Kimberley, South Africa, on February 26th, 1889. He was educated at Bedford School and returned to South Africa to join the staff of Crown Mines in 1907. During the War he joined the Royal Engineers (Tunnelling Company), seeing service in France and Flanders. He attained the rank of Captain and was twice mentioned in despatches. After the War he returned to South Africa, and later became Underground Manager of Modderfontein East. In 1926 he took up the position of Field Superintendent with Messrs. Trinidad Leaseholds, Ltd. Mr. Graham leaves a widow and a son, to whom we extend our deep sympathy.

THE COSTING OF PETROLEUM REFINERY OPERATIONS.*

By Gordon Kerr, M.A., C.A.

SYNOPSIS.

The paper outlines the principles to be followed in arriving at "Process Costs" for the various refinery operations. These costs are intended as a guide to those responsible for the operations, and the preparation calls for joint consideration by chemist, engineer and accountant.

The distinction between Direct Costs, which would cease in the event of a particular operation being discontinued, and Indirect Costs, should always be maintained, and must be borne in mind both in the first segregation of wages, materials and other expenditure, and in determining which processes can be costed separately.

The main classes of expenditure: Direct Costs, Auxiliaries, Fixed Charges and Depreciation, are reviewed, and the method of combining these to show the total costs of each process is indicated. A form of cost statement is suggested.

It is necessary to be clear at the outset as to the ultimate object of the costing system, and in this connection a question which frequently arises in practice is: "What is the cost of manufacturing each one of the products?" Clearly, such information, if obtainable, would be of value to those responsible for marketing the products, but the nature of refinery operations is such that a satisfactory answer cannot always be given. Some part of the operating expenditure of a refinery can no doubt be attributed to individual products, but the main plants produce by one operation, or one series of operations, not one product, but several, and the question of what proportion of the expenditure of operating such plants should be allocated to each product is, from the nature of the operations, capable of no one correct answer. No doubt suitable bases of allocation can frequently be selected in practice to meet particular marketing problems, but no general system of providing "cost per product" can be laid down.

The purpose of the present paper is to suggest a scheme of "Process Costs." A knowledge of the cost of each separate process is, of course, a necessary step towards obtaining a "Cost per product." This final aim is, however, subject to the restrictions already mentioned, and the primary value of process costs lies in obtaining statistics to allow of comparison between the cost of operating the plants from period to period or for one refinery against another, or, in special cases, to provide data for the comparison of alternative methods of working, or to study the possibilities of alternative plants.

With these objects in view, consideration is given below to the questions of, first, what processes should be costed separately; secondly, the analysis of expenditure and its allocation to these processes; and lastly,

* Paper presented for discussion at the One Hundred and Sixty-sixth Meeting of the Institution of Petroleum Technologists, October 8th, 1935.

the form in which the final statement should be presented. In applying the principles suggested below, each step must necessarily be the result of joint examination of the problems involved by the engineers and chemists responsible for operating the refinery and by the accountants. The accountants have available the figures of expenditure, but only with the assistance of the operating staff can these figures be classified and set out in such a way as will present a true picture of the cost of operations. Little value can lie in cost statements which are not drawn up with a full knowledge of the operating facts and in a form which is fully understood by the operators themselves for whose guidance the calculations are made.

Processes to be Costed.

The list of the processes to be costed must necessarily vary from refinery to refinery, but in general it is suggested that separate cost statements should be prepared for each main process given under the headings of :—

Distillation,
Refining,
Cracking,
Gas treatment,
Other refinery operations.

The list may, for example, include for distillation the following :—

1. Crude oil distillation,
2. Distillation of products of special boiling-point ranges,
3. Lubricating oil distillation,
4. Distillation of asphalt residue,
5. Pressure distillate distillation,

and for refining :—

1. Refining of gasoline and kerosine,
2. Refining by the Edeleanu process,
3. Refining of lubricating oils,
4. Refining of pressure distillate.

The preparation of separate cost statements for each of such processes must, however, be subject to certain considerations. Where two or more of these processes are carried out together in the one plant in such a way that the expenditure cannot be stated separately for each process, then only one cost statement should be drawn up. If, however, any one factor in the costs can be allocated as a direct out-of-pocket charge, it may be useful to give this information separately at the foot of the statement. An example of this occurs where gasoline and kerosine are treated in one plant in such a way that the operating expenditure cannot be given separately; in this case only one statement should be drawn up, but the chemicals used should be stated separately for gasoline and kerosine at the foot of the statement. Again, the distillation of crude oil and, say, pressure distillate in the same plant might call for the same arrangement. If two processes are carried out intermittently in the same plant—for example, three months' distillation of crude oil followed by one month's

distillation of pressure distillate, so that important classes of expenditure can be kept separate—then two statements may be drawn up, but these statements must not describe as "direct expenses" items which are in reality the result of arbitrary allocations.

A further case to consider when deciding on the list of processes to be costed, is where several plants or batteries of plants are engaged on one process. In such cases separate statements should be prepared for the individual plants or batteries only if there is some definite object in so doing, and if the operating expenses can in fact be kept separate;—that is, if the analysis of the operating expenditure of the individual units is not the result of arbitrary allocation.

The same test must be applied in determining whether separate cost statements should be prepared for different grades of intake—for example, different types of crude oil—and where only one statement is decided on it may be convenient to show separately on the statement the throughput on basis of weight for the different types and the fuel consumption for each type. Usually, however, if separate cost statements are required in such cases, these should be the result of special calculations based on the total cost of the process for all types of intake modified as a result of actual observations taken during the period in which the special intake is being run. If, however, different intakes are worked intermittently over periods which are sufficiently long to allow important classes of expenditure to be segregated, then separate cost statements can readily be prepared.

The foregoing remarks suggest the cost statements which may be prepared for the main plants, but in addition cost statements should be prepared for such of the following installation processes as may apply to the particular refinery :—

1. Receiving crude oil, etc.,
2. Storage of crude oil, etc.,
3. Storage of finished products,
4. Bulk delivery.

The costs of receiving (1) and storage (2) of crude oil may be combined where no particular purpose is served by keeping them separate, and where the principal costs of receiving are not borne by the installation, but by, say, tankers delivering by their own pumps. Bulk delivery (4) may cover not only products, but may include also crude oil, in cases where part of the crude oil received by the installation is re-delivered as such.

A distinction must be drawn between installation storage and refinery or plant storage. Broadly speaking, the expenditure in connection with run-down tanks and intermediate storage should be regarded as part of the cost of operating the main plant concerned. On the other hand, the large tanks in which crude oil and finished products are stored should, as indicated above, be costed separately, and not included in the costs of any individual plant.

A similar distinction should be maintained in regard to pumping operations. Pumping operations to and from plants and tanks within the refinery should be regarded as forming part of the plant operations. The expenditure in connection with the receiving of crude oil and final delivery

of finished products should be regarded as two distinct processes, and not included in the costs of any of the main plants.

Analysis and Allocation of Expenditure.

In its simplest form the expenditure of a refinery can be stated in terms of the totals of the pay sheets and salary lists and the total value of materials and chemicals issued. In addition there are, of course, other out-of-pocket expenses, such as taxes, royalties, rents, etc. In its simplest form, the per ton cost is the total expenditure divided by the throughput. The value of the costs of the individual processes must depend largely on the original distribution of the wages, salaries, materials and other classes of expenditure among the different operations and activities of the refinery. This original distribution should give an analysis of the expenditure according to its natural segregation under plants, installations, services and the necessary headings for administration and overheads. No expenditure should be charged to any heading other than expenditure which is out-of-pocket to that particular heading. If this principle be lost sight of, and if forced allocations are introduced into the original distributions, then the distinction between direct expenditure and indirect expenditure necessary for good costs will not be achieved, and sound interpretation of the final figures will be impossible.

An example of this distinction may perhaps help to clarify this principle of adhering to an out-of-pocket basis when making the original distributions. Thus, in the case of a refinery which is organized by departments, no expenditure should be charged to a department other than expenditure on salaries, wages, materials, etc., for which the head of that department is held responsible. This is the only way in which the department can segregate from the total costs that expenditure which is its direct responsibility as distinct from that expenditure over which it has no control. In addition, the strict out-of-pocket basis permits of a proper examination of the problems involved in the shut-down of a particular plant or in an alteration in working methods. To take the case of a Distillation Department comprising several distillation units and one process pump-house, it is suggested that the expenditure of the department should be analysed in the first place to show the direct out-of-pocket cost of each of the distillation units and of the pump-house. The reason underlying this recommendation is that since the pump-house does not serve one only of the distillation units, the expenditure on pumping may not be regarded as part of the direct expense of the distillation units. These same considerations arise in connection with certain services which would normally be rendered by other departments. For example, water may be supplied by, say, a Central Engineering Department operating a water station which supplies not only the distillation department, but also other departments of the refinery. In these circumstances no part of the cost of operating the water station can be regarded as out-of-pocket to the individual distillation units, and in the original classification of wages, salaries, materials, etc., the expenditure on operating the water station must be charged to the account of the water station itself, and must not be the subject of some "behind the scenes" allocation to the distillation and other plants served,

which would result in confusion with those expenses which are incurred directly through the operation of the main plants themselves.

In preparing the final cost statements, it is, of course, necessary to allocate to each plant its appropriate share of the expenditure incurred on the various indirect services, but it is essential to good costing that no such allocation of indirect expenditure should be permitted at this first stage. This distinction between direct and indirect expenditure should be maintained throughout the process of building up the final costs, and should be indicated clearly on the face of the final cost statements.

It is recommended that the expenditure and unit costs should be stated on the cost statement for each process under the following main groups and in the order given :—

1. Direct costs (*i.e.* of the process itself),
2. Auxiliaries,
3. Fixed charges and overheads,
4. Depreciation.

The definition of these groups, their allocation to processes and the sub-divisions of each which may finally be shown on the cost statements are given below. The definitions are necessarily broad. They are intended to give a general indication of the main groupings of the expenditure, and should be read in conjunction with the sub-headings given for each group.

Direct Costs.

This expression is defined as expenditure which is due to the operation of the particular plant or process, and which would cease in the event of the operation being discontinued.

The expression does not include all those items for which a convenient basis for charging directly can be found. For example, plant depreciation, fire insurance, and in some cases rents and taxes can all be attributed directly to individual plants. They are, however, fixed charges without relation to the operation or temporary non-operation of the particular plant, and cannot therefore properly be considered as direct operating costs.

It follows from the definition that no charges can be included under "direct costs" which do not arise directly from the natural distribution of wages, salaries, materials, etc. The principles governing this distribution have already been discussed. Any charge which is the result of a forced or arbitrary allocation should not be described as "direct cost" of a process, but must fall under either "auxiliaries" or "overhead." Under the definition, the expenditure on such operations as plant storage and pumping or plant supervision will only be regarded as forming part of the direct cost of a process if the expenditure has been incurred solely in connection with that process. If the operations of pumping and storing or supervision extend also to other plants, they cannot be regarded as direct to any one unit, and should be considered along with auxiliaries as discussed below.

The sub-divisions of "direct expenses" to be shown on the cost statements will, of course, depend largely on the particular processes, but the

following sub-divisions will appear in most cases. The list may further serve to illustrate the type of expenditure to be classified as "direct" and to mention certain points of detail which are likely to arise in practice.

Operating.—This may be further sub-divided into salaries, wages, materials and sundries. This detail is almost essential for purposes of comparing the costs with an earlier period or with budget estimates, and the information is readily available from the original distribution of expenditure.

Maintenance.—The same sub-divisions as for "Operating" should be adopted.

It is suggested that maintenance may be defined as covering work including clean-out work and minor plant alterations carried out by the regular operators of the plant during shut-down time or work carried out by separate maintenance gangs.

Chemicals—that is, chemicals used for purposes of treating oil. Chemicals used for the treatment of boiler water, medical supplies, etc., or to combat corrosive elements, should be regarded as ordinary consumable materials, and would therefore appear under "Operating materials."

Fuel.—Fuel consumed directly on a process is, of course, a direct expense of that process. If purchased, it will have a value which will appear on the cost statements, but if the refiners' own product is used, it is suggested that no value should be included. The quantity and quality of purchased fuel and own production and also percentage to intake should be shown at the foot of the statement.

Insurance.—Certain types of insurance form part of the direct costs, *e.g.* Workmen's Compensation or Sickness Insurance, and other insurances which vary with wages may properly be taken up along with wages. Insurance of oil stocks is also a direct charge to the process which bears the other expenses of storage. Fire Insurance of plants and installations is to be regarded as a fixed charge, and should not therefore appear under "direct expenses."

The foregoing is not, of course, an exhaustive list of the types of direct expenses which may be met with, but enough has been mentioned to illustrate the principle and suggest the sub-divisions which would appear under this heading in the cost statements.

Auxiliaries.

This expression is intended to cover services which at least to some extent vary according to the operation or non-operation of particular plants, and which can be readily charged to plants according to consumption or some other measure of the service rendered. Under this definition auxiliaries will include such services as:—

1. Gauging,
2. Main pump-house,
3. Oil and gas lines,
4. Intermediate storage and pumping,
5. Recovery of sludge acid, etc., for oil,
6. Plant supervision,
7. Laboratory.

In as far as expenditure under these headings (and such other similar services as may occur in a particular refinery) is not directly attributable to one main process, it must be treated as an auxiliary. If the expenditure is, however, attributable to one main process, it should be included with the direct costs of that process.

The expression "auxiliaries" as defined also includes the following :—

1. Water,
2. Steam,
3. Electricity,
4. Compressed air.

In the cost statements each main process must bear its share of the total expenditure on auxiliaries, and some suitable basis of allocation must be found. In the case of the first type of service listed above, some measure of the service rendered is usually available, *e.g.* quantity pumped or time occupied. The cases of water, steam and electricity differ from the first list inasmuch as they can, and *should*, be reduced to a unit cost basis. All these can be charged out as a definite number of units consumed to each main process, and therefore the unit cost should be determined. This is not true of the other seven auxiliaries, as they do not lend themselves either to costing on a unit basis or to allocation on such a basis.

Each cost statement should show under the heading "Auxiliaries" one figure only for its share of the direct expenses of each auxiliary. The allocation to main processes of the depreciation on auxiliary plants and of the share of the fixed charges applicable to auxiliaries should be made on the same basis as adopted for the allocation of the direct expenses of the auxiliaries, *i.e.* consumption or other suitable measure, but the charge against each process for its share of this depreciation and fixed overhead should be shown on the cost statement under the headings of "Depreciation" and "Fixed Charges" respectively.

Fixed Charges and Overheads.

This expression covers broadly all classes of expenditure which will not vary with the operation or non-operation of a particular plant, or will vary only slightly, and then only in consequence of the final or a long period shut-down of the particular plant.

Under this definition the expression will include all out-of-pocket expenses which cannot properly be regarded as "direct expenses" of processes or auxiliaries, and expenditure such as fire insurance on plant, fixed royalties or fixed rents will fall under this heading, even though a natural basis for direct allocation to main processes can be found. When such a natural allocation basis can be found, it should be used if the amount is of sufficient importance to warrant separate treatment. It is usually possible to allocate many single items on some specially selected basis appropriate each to itself, but while this will no doubt achieve a greater degree of accuracy, the difference in the final result may be negligible, and the method, if applied to small items, is cumbersome, and may cause an unwarranted increase in costing staff.

All remaining fixed charges should be allocated to processes and auxiliaries in proportion to their direct working expenses, but excluding from the direct expenses items such as chemicals, direct royalties and direct fuel. In effect this reduces the basis closely to the basis of direct wages, salaries and materials, and gives some reasonable measure of the various activities, and whilst it is not claimed that this is the only basis that can be found, it is believed that in practice it will be found to give satisfactory results. A basis which is sometimes adopted for the allocation of fixed charges to processes is throughput. Throughput has, however, little or nothing to do with the relationship of fixed charges to particular plants. A distillation unit which puts through 2,500 tons of crude oil per day cannot in reason be charged with ten times the share of Management, Office staff and General Services charged to, say, a lubricating oil plant capable of handling a throughput of 250 tons per day.

That portion of the fixed charges which is allocated to auxiliaries in the first place is, of course, subject to further allocation to the main processes, and, as explained above, this allocation should be done on the consumption basis or other basis chosen for the allocation of the direct expenses of the particular auxiliary. All overhead, however, whether allocated directly to processes or indirectly via auxiliaries, should be shown on the cost statements under the heading "Fixed charges."

Important expenditure, such as fire insurance, as explained above, which may be allocated on a special basis, should be stated separately on the cost statements. Apart from this, only one figure should be necessary for the proportion of the remainder of the fixed cost.

Depreciation.

It is recommended that depreciation should be shown on the cost statements under the following headings:—

Direct Depreciation.—That is, depreciation of the plant, installation, machinery, etc., used in the process to which the particular cost statement refers.

Depreciation on Auxiliaries.—That is, the share which has been allocated to the process in accordance with the principles of allocation already suggested.

Depreciation on General Facilities.—That is, the proportion of this depreciation which as the result of allocation is charged to the particular process.

Depreciation on idle units of running plants or part units should be included in the depreciation of the running plant. Depreciation of idle plants, if not definitely out of use and intended to be dismantled, should be taken up under general depreciation.

Form of Cost Statement.

It may be well to give here some particulars of the form of cost statement which, if the above suggestions were followed, would be arrived at for each main process. It will probably be found advantageous to show not only the cost per unit of intake, but also the total expenditure.

The expenditure for the period and the cost per unit of intake might, in a simple case, if the classification indicated above were followed, be shown under such grouping and headings as follows :—

Direct Expenses

Operating (sub-divided into Salaries, Wages, Materials, and Sundries),
Maintenance (sub-divided into Salaries, Wages, Materials, and Sundries),
Chemicals,
Supervision,
Intermediate Storage and Pumping.

Auxiliaries

Laboratory,
Main pump house,
Steam,
Water,
Electricity.

Fixed Charges

Fire Insurance (Direct),
" " (Ex Auxiliaries),
General (Direct),
" (Ex Auxiliaries).

Depreciation

Direct,
On Auxiliaries,
On Overhead Facilities.

It will be appreciated that these headings will not occur in the cost statements of every process, and for some processes additional headings will appear. Moreover, for the reasons already given, the items " Supervision " and " Intermediate Storage " may appear as " Auxiliaries." These questions can only be settled on full knowledge of the conditions of operating.

In addition to the expenditure and cost figures, for a proper understanding of the costs it will be found useful to show on the cost statements certain consumption and quantity data. The principal items are mentioned below :—

(*a*) The quantity of each grade of oil intake should be shown separately, together with, if possible, the average specific gravity at 15° C. (60° F.). It may be convenient to state also at the foot of the statement the rates of throughput in weight per day for the different grades of intake and the fuel consumption for each grade.

(*b*) The quantity ex each Utility (Water, Steam, etc.) consumed directly in the process.

(*c*) The quantity and price of each chemical. Where the chemicals cannot be attributed to individual products, the value can be shown on the cost statement as a direct operating expense of the process. Where the chemicals are attributable to individual products, the value should be

shown at the foot of the cost statements with an indication of the products chargeable.

When sludge acid is used, the consumption of fresh acid should be stated with values, together with the quantity of sludge used without value. The estimated refining value of sludge as compared with fresh acid may perhaps usefully be added : thus, 100 kilos of sludge = 80 kilos fresh.

(*d*) Fuel consumed has already been referred to. In the case of purchased fuel, the quantity and price charged should be shown. In the case of consumption of the refiners' own product, it is suggested that quantity only should be given. Total consumption during the period covered by the cost statement should be given, and also the percentage of consumption to intake. This information regarding fuel should show the quantities used directly on the particular process separately from the quantities allocated to the process as its share of the fuel used by auxiliaries and overhead facilities.

It is perhaps necessary to add some word regarding the frequency with which these cost statements should be prepared. For ordinary purposes of control of expenditure from week to week or month to month, the original distribution of expenditure under its primary headings and without allocations of either auxiliaries or overheads should be sufficient. The preparation of full cost statements including these allocations necessarily involves a good deal of clerical work; moreover, it must be remembered that short-period costs are liable to be misleading. The period chosen should, therefore, be sufficiently long that special temporary circumstances are unlikely to have undue weight, and for practical purposes it is recommended that these cost statements should not be prepared more often than half yearly. In most cases it will be found that the purpose of costing will be better served if complete cost statements are prepared not oftener than annually.

EXAMPLE OF COST STATEMENT.

Distillation of Crude Oil (inclusive of Redistillation).

	1934.		1933.	
..... crude	... M. Tons	Sp. Gr. 0·914	... M. Tons	Sp. Gr. 0·912
..... "	... "	" 0·955	... "	" 0·957
..... "	... "	" 0·891	... "	" 0·891
	... M. Tons	Sp. Gr. 0·935	... M. Tons	Sp. Gr. 0·925

	1934.			1933.	
	Total Cost.		Per M. Ton Intake.		Per M. Ton Intake.
Operating :					
Salaries	...		...		...
Wages	...		...		...
Materials	...		...		...
Sundries	...		...		...
Maintenance :		...		...	...
Salaries	...		...		...
Wages	...		...		...
Materials	...		...		...
Sundries	...		...		...
Supervision		...		...	...
Intermediate Storage and Pumping		...		...	...
Total direct costs		...		...	...
Auxiliary Processes :					
Laboratory	...		...		...
Main Pump House	...		...		...
		...		...	...
Utilities :					
Steam	...		...		...
Water	...		...		...
Air	...		...		...
Electric Current	...		...		...
		...		...	...
Fire Insurance :					
Direct	...		...		...
ex Auxiliaries	...		...		...
		...		...	...
		...		...	...
Refinery Overhead		...		...	...
		...		...	...
		...		...	...
General Overhead :					
Direct	...		...		...
ex Auxiliaries	...		...		...
		...		...	...
Total excl. depreciation		...		...	...
Depreciation :					
Direct	...		...		...
on Auxiliaries	...		...		...
on Overhead Facilities	...		...		...
		...		...	...
Total		...		...	...

	1934.				1933.	
	M. Tons.		% on Intake.		% on Intake.	
Fuel Consumption (not valued):						
Direct . . .	...		...		...	
ex Auxiliaries . .	...		...		...	
ex Overhead Fuel .	...		...		...	
		...		...		...
Specification of Fuel Consumption.	Residue.		Gas.		Gas oil.	
M. Tons:	1934.	1933.	1934.	1933.	1934.	1933.
Direct . . .	...	...	...	...	...	...
ex Auxiliaries . .	...	...	...	...	...	...
ex Overhead Fuel .	...	...	...	...	...	...
Total . . .	...	...	...	...	...	...

Consumption data:
Steam (direct) . . . . M. Tons.
Water . . . . ,,
Electricity . . . . Kwh.

	Throughput.	Fuel Consumption % of Intake.
..... crude	... M. Ton per Day.	...%
..... ,,	... ,, ,,	...%
..... ,,	... ,, ,,	...%

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE One hundred and Sixty-sixth General Meeting of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, W.C., on Tuesday, October 8th, 1935. In the absence of the President (Sir John Cadman), the Chair was occupied by Dr. F. B. Thole, who expressed the President's regrets for his unavoidable absence.

The Chairman, in introducing Mr. Gordon Kerr, said the paper introduced a fresh and most important aspect of the industry. They all recognized that neither production, refining nor distribution could be carried out with the degree of efficiency now existing, were it not for the skill and the guidance of those engaged in assessing and allocating the costs of the operations.

Mr. Kerr had had long and exceptionally wide experience in refineries, both at home and abroad, which handled a variety of crude oils and manufactured a wide range of products, and the extent of his knowledge of the problems thus involved would render his discourse particularly valuable.

The following paper was then presented :

THE COSTING OF PETROLEUM REFINERY OPERATIONS.*

By GORDON KERR, M.A., C.A.

DISCUSSION.

The Chairman, in opening the discussion, said that while the title of the paper was limited to refinery operations, the systematic classification and the fundamental principles which the author had expounded could no doubt be adapted to deal with other aspects of the industry. There were present at the meeting many with managerial experience in refineries who were doubtless anxious to express their views on Mr. Kerr's paper. He, as a layman in accountancy, had but one question to ask, and that was on what basis Mr. Kerr allocated the value and cost of products which were waste from one section but applicable to another section of the refinery—such as low-pressure steam from a turbine which could be used for distillation purposes.

Mr. J. Kewley said that Mr. Kerr certainly realized the necessity of close co-operation also with the actual plant operator, who was the only man who could give an authoritative view as to how certain sums should be allocated.

He pointed out that there was an important difference between the petroleum industry, which split up and analysed a single raw product into a number of components, and an industry which built up or synthesized a single finished product from a number of components. The costing in the

* See pp. 907–918

latter case presents little difficulty, but in the former case a number of problems occur, for example, how to compare the cost of distilling for gasoline with that of distilling for residue. Therefore, in the case of the petroleum industry an element of uncertainty had to be introduced into the figures, which could be avoided in the case of a synthetic industry.

One important question was the way in which certain overhead expenses were to be allocated. Many diverse views could be held on that subject. Mr. Kerr had pointed out in the paper that to allocate overhead charges according to direct working expenses was practically tantamount to allocating those charges according to labour charges. That was simple, but would not operate fairly in a refinery which might have a very expensive plant, such as a modern extraction plant, requiring little to be spent on it in the way of upkeep and repair, with operating costs consequently less than those of a rather cumbersome, out-of-date plant which had cost much less to erect. Therefore he thought it was a mistake to allocate overhead costs principally according to the labour charges, as an expensive plant should surely bear a larger proportion of the overhead costs than a relatively cheap plant.

There was another difficulty which might arise. In the case of a refinery with a number of units working on a number of definite processes, a section might at some time be put out of commission for a period for some cause or other. What was to happen to the overhead expenses which that plant had previously borne? Were they to be held over, or would the other sections of the plant have to bear them? If the other sections of the plant had to bear them, then the putting out of commission of one section of the plant might very seriously upset the working charges of the other operations.

Another problem which must occur to refinery managers is that of estimating the cost of setting up a new operation in a refinery. Strictly speaking, if the already existing refinery was bearing all the costs, then, if one erected a new plant, one should ignore the overhead costs which should normally be allocated to that plant, in order to arrive at the real cost of the operation. Otherwise, if one did allocate them to that plant, then one should decrease the overhead charges in all the other sections of the plant, thus reducing the cost of the other operations. He thought that in that connection there was often a pitfall in estimating what a new operation in a refinery was going to cost.

Mr. N. A. Anfilogoff said he was disappointed at not having received any guidance from Mr. Kerr in the paper with regard to the amortization charges and percentages for depreciation which ought to be allocated to various plants and various auxiliaries. For instance, a plant like a cracking plant costs a considerable amount of money, and also needs considerable amounts of money spent on maintenance, and it might be obsolete or non-existent in three years. One had considerably greater depreciation in that case than in the case, for instance, of the cylindrical still or the tube still, which would last for generations. On the other hand, in the auxiliaries, for instance, Mr. Kerr had one tank which he called a direct charge on the refinery because it happened to store the products of crude oil, and at the same time he had a similar tank as an auxiliary charge because it happened

to store crude oil. Was there any differentiation in the allocation of depreciation on those two tanks? On the other hand, there were certain receiving tanks which, if one was dealing with types of crude oils which were rich in sulphur, for instance, would have a considerable amount of wear, corrosion, and so on. What differentiation did Mr. Kerr make between the amortization on that tank and the amortization on the tank which stored, for instance, lubricating oil, and which would last for a hundred years? Again, what differentiation did Mr. Kerr make between the amortization on the pump he used for pumping acid or acid sludge, which would last for a month or two, and the amortization on the pump in the pump-house, which would last quite well, without much looking after, for thirty or forty years? Those were points on which he would have liked Mr. Kerr to give a lead.

The next point he wished to mention was this. His own experience was that when the workman or the operator was given a card and asked to put on the back of the card the number of hours he had spent on this and that job, he went on working until five minutes to the knocking-off time, and, when he had to put on the back of the card what he had done, he said to his mate: "Well, how long were we on that, mate?", and the figure his mate gave was the figure with which the accountant had to deal!

His experience was that labour was the cheapest thing which had to be considered so far as the refining costs were concerned. Coal, chemicals and steam were the most expensive, apart from the cost of the plant. From his experience he had found that, if the manager went round the works and stopped a steam leak which did not look very much but was merely a little spit now and again, if that was translated into hundredweights of coal per week it would probably make a difference of twopence or threepence a ton in the cost of refining.

His view was that the job was a very difficult one, and the refiner could not help a great deal, nor could the refiner or the operator or the works manager, for instance, allocate correctly the costs when it came to overheads, because there were such things as managing directors, offices, and so on, and the cost of all that had to go on to every gallon manufactured or sold. Therefore the job was simply an office job. The most the works manager could do was to give, either himself or by means of accountants or cost clerks, an accurate analysis of his wages sheet, an accurate analysis of the stores and labour used in maintenance, an accurate analysis of the wages and the costs—not necessarily the cost of material, because the office would know that, but the labour and the material employed on new works as capital costs. Then presumably the works manager ought to send that up to the city office, and trust in providence that the accounts department would carry out the proper allocation.

Mr. A. A. Ashworth said the paper showed that Mr. Kerr had an intimate knowledge of the subject treated, but he thought it should be borne in mind that a true costing accountant for refining must be not only a very good accountant, but also a technical man. It was almost impossible for him to derive from those in charge all the technical facts that he needed; it would probably take up too much of his time; he himself must know intimately the general processes which he was costing.

In the past he had been urged very strongly to put in a costing system at a refinery in order to value each product at the end of the month, because it was only by getting the cost value of that inventory that a true statement of the position at the end of each month could be obtained, but when it came to obtaining the cost value of each product, one was faced with so many arbitrary divisions of various expenses that it became almost hopeless to try to arrive at a real cost value; one would have to divide the crude oil into its value with reference to each special product. The crude oil came in containing potentially so much kerosine, so much gas oil, etc., but how was the value of the raw material for each product in that crude oil to be apportioned? Again, various general expenses also had to be divided in a very arbitrary way, and really the figure arrived at, after a great amount of trouble in preparing a costs statement, would bear a very remote resemblance to the actual cost value of the product in question. In the end it had been found that the only possible course to adopt was to value the product in storage on the basis of past operations and say: "Well, the selling value is so much and the cost of running the refinery is so much, and that indicates so much profit; take off so much profit from the selling value and put the value of that inventory at that price."

Mr. J. A. Oriel said there was no question, he supposed, that costing statements were of great value to all those connected with the petroleum industry, and throughout all industries costing was now definitely an accepted fact. So far as he was concerned as a practical refiner, he had no quarrel with the accountant so long as the accountant dealt only with what Mr. Kerr had referred to as out-of-pocket expenses. Up to that point he felt on fairly firm ground and agreed with Mr. Anfilogoff that, so long as one knew exactly what was being debited to a plant, one knew where one stood. In the out-of-pocket expenses he would be inclined to include such things as steam, air and electricity, which could definitely be measured in some way to a particular plant. When one had finished with that part of the costs, one came to the allocation or the "fudging," so dear to the heart of the accountant, and with regard to that he must say that he did not feel at all happy. The whole of the discussions on costing related to the allocation of overheads and how they could best be allocated, what system was to be adopted, and so on, but these allocations were so frightening to him that when he had a costing statement in his hand he was never quite certain, once allocation commenced, what it really did mean. Included in the overheads were such things as management, office staff, watchmen, general expenses, and so on, and as to how they should be allocated to the different plants he did not feel sure. Such expenses would continue whether the plant was shut down or not; if the plant was completely abolished, there would still be those charges. He suggested that refinery costs should include the direct or out-of-pocket expenses; when he said that, he [illegible] the things that could be measured accurately or definitely allocated to a particular plant. He felt that one should consider the reason for making cost statements. First of all, one might say that they were wanted for the purpose of controlling the price and determining what should be charged for the products, but he thought that in the present state of the petroleum industry the cost of refining had little or nothing to do with the actual selling

price of the material, that being controlled by a variety of factors over which the refiner had no control. Secondly, cost statements might be used for the guidance of the local management. The local manager wanted to know what he was spending from month to month on the particular processes, and for that he wanted his direct expenses; he wanted a small sheet of paper showing him plainly what certain plants had cost him to run during the month. Personally he knew that after the first half of the statement which related to direct costs, he did not feel so certain about it, because he was aware that the remaining costs had been allocated merely according to some arbitrary plan. Lastly, cost statements were wanted for the purpose of making comparisons between various refineries, ascertaining the advantages of erecting a plant at one place instead of at another, and so on. That question cropped up about once every four or five years; new plants were not built every month. It would be just as well if the refiner were given a plain statement of what his costs were monthly or every three months, and then the allocation of overheads, and so on, could be done when the necessity arose, when the question of erecting new plant cropped up. That would in every way be very much better, because at that particular time all the pertinent questions regarding the erection of a new plant and how the building of a new plant would affect the overheads would be brought to the surface at the time of the consideration of the erection of new plant. The whole matter would be made very much simpler if refiners could indulge in "fudging" once every four or five years, instead of once a month. He felt that, if they had to "fudge," Mr. Kerr's method was well thought out and one of the best methods of "fudging," but he thought that "fudging" should be cut down to a minimum.

Dr. F. H. Garner asked if Mr. Kerr would give the reasons for the suggestion that if the refinery fuel were used no value should be included in the cost statement. It had already been pointed out by Mr. Anfilogoff that fuel and steam were very important items in cost, and attention had also been directed to the relative ease of measurement of these two items. Since these items were a very important part of the direct expenses, they would also affect those indirect expenses of which the allocation was based on the direct cost.

Mr. N. A. Anfilogoff said there was one point which he wanted to make clear. So far as costing was concerned—not accountants' costing in a city office but costing in the works—the works manager would be in a very great difficulty if he did not know what his operations were costing him not only once in six months but almost daily. He must have an analysis before him almost every day, otherwise he could not tell where he was going wrong. That was done, of course, by the local works man.

R. R. Tweed said he had listened with very great interest to the discussion, which it seemed to him had been confined so far to what he might call the inner working of a refinery, and that was of particular interest to the refiner himself, but the question was of very great importance to the whole industry, from the point of view of the very large number of people who sold crude oil to refiners, because one of the factors on which the price of crude oil was based was the refining cost.

He had been particularly interested in the statement that there could be, for example, separate cost statements for different types of crude oil, and it was on that question that he wished to make a few remarks. He quite agreed with a previous speaker in the discussion who had said that, with regard to the direct costs, *i.e.* the out-of-pocket expenses, there would be no difference of opinion, but when one came to the question which loomed very large in all such matters, that was, the indirect costs—overheads, depreciation, etc.—Mr. Kerr said he would also allocate those according to the direct out-of-pocket refining expenses. Referring to the costs of refining different types of crude oil, he had heard it contended that the time taken to refine the different types of crude oil should be used as a basis on which to allocate the overhead charges. He understood that Mr. Kerr had rejected that, as the time basis was not referred to at all in the paper. He did not agree with Mr. Kerr, however, that the allocation of overhead charges should be based on the direct cost of refining different types of crude oil. When, for example, it was a case of having one crude oil which cost a certain amount to divide into two or three products, and another crude oil which cost double that amount to divide into the same products, he agreed with Mr. Kerr as to the direct costs of refining. With regard to pumping, however, surely it cost no more to pump gasoline from an expensively refined crude oil than it did to pump it from a less expensively refined crude oil? Why should more be charged for storing gasoline from one crude oil as compared with that from another crude oil because from the first crude oil it cost more to obtain that product? Likewise, with regard to other fixed charges, the allocation should not be based on the direct cost of the refining of products, because surely one would not charge more for London office expenses or measuring or gauging the products because one had a type of crude oil which was more expensive to refine than other crudes? It was on that point, the allocation of the fixed charges, that he did not agree with Mr. Kerr.

Mr. R. C. Paterson said he had hoped to hear something from an expert accountant about the use of refinery costs as a guide to the selling price of the products, but that fallacy had been laid bare, and so refiners were thrown back on to other methods of obtaining some idea of the true value of the products. He thought the difficulty of arriving at separate distillate costs when a comprehensive type of plant was being operated, perhaps giving five side-streams, was really almost insuperable, but some kind of approach to the actual cost of those side-streams could best be obtained if a factor was introduced into the calculation which might be said to be related to the market value of the individual products. It was manifest that, although it might be difficult to arrive at the cost of an overhead fraction like gasoline, and separate it from one lower down, such as kerosine, yet it was necessary that some sort of determination should be made, and it would be very interesting to have Mr. Kerr's views on that point. The same thing might be said about the bottom residue from the distillation process, such as bitumen, fuel oil, or whatever it might be.

On the matter of allocation of overheads, he had listened to the remarks which had been made by the various speakers in the discussion, but he

had not heard anyone bring out clearly the fact that in making up the complete cost there were two kinds of overheads to be dealt with. One might be called works overheads, and the other the general overheads, which comprised all the usual and special expenses arising from administration and marketing. Surely, for the purpose of stating the refining costs, if one dealt simply with the works side of the matter, it was only necessary to concern oneself with the works overheads, and expenses under this head were known in amount with a fair degree of accuracy for the whole year, and they must be properly absorbed in the statement of works costs. Therefore there must be allocated a proportionate weekly sum to be charged to the individual producing unit of plant, and it seemed to him that very little useful data could be obtained if one did not make some attempt to attack the problem in this way. He thought it would scarcely do to produce detailed costs only twice a year or even quarterly; that might lead to a serious misunderstanding of the situation, and he could see no major difficulty in arriving at a statement of the cost of operating a particular plant over a short period such as a week. Moreover, if there was one plant producing and another plant alongside of it idle for part or whole of the period, one must in some way allocate to the idle plant part of the general burden of cost, so that when it came on to production again the average cost was properly shown over the period covered by the statement of cost. The errors arising from short period costs prepared in this way are easily eliminated by cumulative sets of figures and average unit cost obtained over the extended period.

He was in full agreement with Mr. Kerr's statements as to the distribution of direct and indirect expenses arising from the operation of the particular plant or process and, as he had already said, he would be grateful for some guidance from Mr. Kerr as to the actual determination of the costs on the separate fractions.

Mr. E. A. Evans said that it was very refreshing to be told by a man of finance that there were so many difficulties in the way of accurate costing in the petroleum industry that it was almost impossible to cost any one product accurately. A chemist is frequently being accused by commercial men of a want of accuracy and definition, and that he invariably leaves himself a way of escape when he has expressed himself. Apparently it is a perfectly simple thing to cost a product from out-of-pocket expenses, but in a complex industry such as ours it must be extremely difficult to make proper allocation of overhead charges. What are overhead charges, and how are they arrived at? The discussion has indicated that this is a subject of complexity and difficulty. If there is all this difficulty about costing and allocation, how much more difficult and uncertain must be the subject of fixing selling prices. It would probably be argued that the selling price bears no relation to the cost price. That may be true, but the overhead charges must carry in their wake the cost of selling. Perhaps it might be extremely interesting to carry the discussion a step further and stage a meeting to discuss selling prices! Apparently, after all, the man of science need not exhibit his natural timidity about the limitations of his methods when one knows that the man of finance has his limitations of accuracy.

Mr. E. E. Leigh said there were one or two points with regard to which he was in a little doubt. Mr. Kerr suggested that when a product was treated alone in a plant—for instance, kerosine perhaps going into an SO_2 plant—it would be better to call that kerosine treatment; in other words, regard it as a process account; whereas, when a certain plant treated more than one product, he understood that Mr. Kerr favoured the costing of the expenses under plant. He would like to ask Mr. Kerr if he was in favour of presenting to the management a statement composed partly of plant costs and partly of process costs, and, if so, whether he thought that would give the management any help. Personally he did not think it would.

With regard to fuel, Mr. Kerr suggested in his paper that if it was the refiner's own fuel, it should not be taken in at any charge. How did he propose to deal with the case in which both purchased fuel and the refiner's own fuel were used, and how did he propose to deal with processes which used the refiner's fuel one month and purchased fuel the next month? And what would the sales department say to his suggestion of taking the refiner's fuel in at nil?

He did not quite understand why Mr. Kerr suggested that cost statements should be submitted half-yearly or possibly annually. It seemed to him that behind the suggestion there was an inherent fear about the overhead charges which had been referred to so frequently in the course of the discussion that evening. Did not Mr. Kerr think it possible that at the beginning of the year most of the overhead charges could be fairly well estimated, and that exceptional charges would not crop up with very great frequency?

Mr. Frank Levy, in a written contribution, said in connection with "maintenance," it is as well to include as many plant alterations and replacements as possible, especially where no great amount of capital expenditure is involved. One of the chief cost items in all modern chemical plant operations is obsolescence: it is really more important than depreciation. A plant, more often than not, does not "wear out," but it is replaced by something more convenient or up-to-date within five years, or else has to be modified to meet more stringent market requirements in the finished product. If any part of such modification can be written in as maintenance, then the difficulty of making the necessary provision for "renewal" can be in some measure overcome. Moreover, plant managers are usually allowed some measure of discretion in these matters, and a certain amount of money can be spent without requiring higher sanction. He could agree that a refiner's own product—say, fuel oil for heating purposes—should not be charged. First, it is not possible to arrive at the real cost of any single operation unless it is taken into account, and, secondly, the plant producing the said fuel oil cannot be put on a satisfactory profit and loss basis unless it is credited with the value of the whole of its production. A very safe basis is to charge the plant using the fuel oil (for example) with the ex works naked price, which would be obtainable for the product had it been sent out of the refinery. Since this figure will always show a saving as between the actual price allocated and the cost of buying the same quantity of material outside on the open market, it would seem to offer a very fair compromise on the matter.

The objection raised by Mr. Kerr to the "throughput basis" for the allocation of fixed charges may equally well apply to his own basis of direct expenses. Under his scheme, for instance, a case and canned-good department would be saddled with a very heavy charge, whilst a special distillation plant may escape lightly. Whatever basis of allocation is applied to fixed charges may, in this event, have to be used for some of the auxiliaries also, and this would make the disparity mentioned above still more apparent.

With regard to fixed charges and depreciation, it seemed to him to be simpler to throw the whole cost entailed in any particular service on to the charge to be made for that service. Thus, the cost per unit of electricity should cover depreciation, insurance, etc., of the generating station and transmission equipment, so that Depreciation on Auxiliaries or General Facilities do not appear as separate items.

Finally, although the scheme so lucidly outlined may indeed be ample from the pure accountancy point of view, it is not quite sufficient either to establish whether each plant manager is running his own department efficiently, or to compare costs incurred on different refineries each carrying out a similar series of operations. It is not possible, for instance, to ascertain whether steam, water or power is being used in great excess of what might theoretically be required, whether the plants are over-staffed or perhaps carelessly handled (resulting in excessive maintenance charges or high laboratory costs). There is a great deal to be said for the direct measurement of the various services laid on to each plant—power, water, steam (always provided the refinery is sufficiently large to warrant the charge), for it is not so much in actual cash as in bulk quantities consumed over a period that excessive usage becomes apparent. For these and similar reasons it will also be found that the maximum benefit is obtainable by means of a monthly costing system; admittedly it may be troublesome to instal, but once it has been established it need not be so elaborate as to entail a large extra staff.

Actually on any refinery and most other plants, monthly stock returns and production sheets are generally required, and it would usually be found that to tack a costing return on to these did not require a large amount of additional labour.

Mr. D. G. Hitt, in a written contribution, said: The author, in dealing with the direct costs of an installation, suggests that fuel, if purchased, shall be charged to the installation at the purchase price, but that if it is the refiners' own product, it shall be considered to have no value.

He desired to have Mr. Kerr's reasons for the second statement, as it would appear that in the case where the refiners' own product is used, and where it is saleable, then it should be costed at the price which could have been obtained for it if sold, as this represents revenue not realized.

Naturally, if the product is not saleable—say, for example, uncondensable gases—then, as these would have been blown off to the atmosphere otherwise, he agreed that they should not be charged to the installation if used as fuel.

Thus, for example, the costs of an installation with a furnace burning both oil (saleable) and gas (unsaleable), would readily show the benefits

to be obtained by making the necessary investments to enable a greater percentage of the unsaleable product to be burned.

Mr. Gordon Kerr, in replying, said the question of "fudge" had been dealt with by many of the speakers in the discussion, and he would like to explain in more detail what he had in mind. His reason for saying that the full allocations should not be made more often than half-yearly, or preferably annually, was simply that he did not believe that complete cost statements, containing all the "fudge" to which reference had been made, were of any value at all if they appeared frequently. Mr. Oriel had suggested that they should be produced every four or five years, and he himself had suggested every year; what he was opposed to was their being produced every month. Mr. Oriel had said that he was frightened of the allocations, and personally he agreed with Mr. Oriel in that. From the operator's point of view the really important thing was the direct charge against each process.

For purposes of week-to-week control or monthly control, his idea was that one should have, in the very first analysis of wages and materials, the value of wages and materials used directly on each plant or on each service, and it was those figures which were of practical value to the operator. To add on once a week or once a month or once a quarter the figures for the indirect charges for auxiliaries and overheads was of no value at all to the operator. He would add this, that, if he had the responsibility of running a refinery, he would ask his department heads to make a budget, and that budget would be simply a statement of the salaries, of the wages and of the materials which they expected to spend, say, during the next six months on each plant. He would check them all once a month from the corresponding straight analysis figures without allocations of any sort. Once a year he would have a complete cost statement.

That brought him to the second question which many of the speakers had mentioned, the question of costs per product. There were, of course, all sorts of ways in which product costs could be obtained, and they often had to be worked out. He questioned very much whether they were ever really required for sales purposes; the selling price was fixed by something rather different from the cost of an individual product. He noticed that one speaker had had the misfortune to have to work them out in order to get at the value of stock at the end of the month; that had to be done sometimes, unfortunately, owing to regulations in certain countries. If for this or any other reason it was necessary to get at costs per product, personally he would allocate according to the value of products; he did not say that was correct, but tonnage was obviously incorrect, and he thought the method of allocating costs according to value of products was as good as any other method. For the purpose, however, of providing information for guidance in operating a plant he could not see that the costs per product, which were necessarily the result of arbitrary allocation, were of any help at all.

The question of fuel had been raised by a number of speakers. He did not say that the refiners' own fuel should be considered as of no value, but he had found in practice that, so far as giving information to operators was concerned, owing to fluctuations in the value of fuel it was not worth

while to state a value on the cost statements. If it was useful for any purpose to value fuel, by all means it should be valued. He could not say apart from a particular case whether it should be valued at cost price or at market price, but, apart from that difficulty, there were the market fluctuations, and he believed that for control purposes, which were all that he had in mind, the simpler and more satisfactory method was to hold to the tonnage. In the case of a refiner sometimes using his own fuel and sometimes using purchased fuel, he thought he would value. There might be cases where one was comparing one refinery with another and the question might arise of a refinery using waste gas instead of fuel. In view of these complications he personally preferred to leave the fuel unvalued and state only what grade and what quantity of fuel were used.

The question of amortization had been raised by Mr. Anfilogoff. He was afraid he had rather shirked that question, but the reason was exactly the difficulty which Mr. Anfilogoff had expressed. Circumstances, of course, must guide one in deciding what rate of depreciation or amortization should be included in the costs. In the case of a plant with a short life there must obviously be a higher rate than in the case of a plant which would last a long time. In his experience, however, it was almost impossible to say how long a plant would last. Depreciation was not an exact science, and for that reason a number of refiners had decided that the simplest and best course to adopt was to take a flat rate of 10 per cent. all round. Some plants would last for five years, some for ten years, and some for twenty years, and some tanks might last for a hundred years. The fact was that no one knew how long they would last. Apart from these questions of physical life there was the question of possible useful life. A refinery might be dependent for its supply on one field, and the usefulness of a refinery might depend entirely on there being oil available. Further, there was the question of obsolescence. It was altogether too indefinite a question to discuss, he thought, and for that reason he had omitted it. All he could say was that, if a refinery manager considered he could estimate with reasonable certainty the lives of his plants, then by all means let him so calculate his depreciation rates; otherwise he might just as well keep to 10 per cent. all round.

Steam had been mentioned as an out-of-pocket expense, and he thought that was not really the case. A steam plant would serve quite a number of processes, and the stopping of one process would not necessarily mean a direct saving in the expense of running a steam plant; it would mean a saving to some extent, possibly, but it would not mean an exact proportionate saving. For that reason steam and water and other such items, which he had called the auxiliaries, lay midway between overheads and true out-of-pocket expenses. He would therefore show them quite separately on the face of the cost statement, avoiding mixing up the figures with the direct expenses and equally avoiding mixing them up with the overheads. If the question of shutting down a plant arose, it was a matter of using one's judgment as to what saving there would be on the steam plant.

There was one point to which Mr. Anfilogoff had referred with regard to which he wanted to make clear what he had in mind. Mr. Anfilogoff had mentioned the case of operators allocating overheads, but he did not

suggest that they should do that. The work which he thought operators ought to do was nothing more than allocating the wages, the salaries and the materials that their own men used. The allocation both of auxiliaries and of overheads had, of course, to be done in the office. The only point was that the operator should know what basis was being used.

The Chairman had raised a point in connection with waste steam or waste products from auxiliaries, and there was a reference in the paper which perhaps to some extent met that point. His idea was that the consumption of, say, fresh acid should be charged to the plant in which the fresh acid was used. If there was sludge acid, then he considered that no value should be placed on it. The simplest method to adopt was to make some estimate of the refining value of the sludge as compared with fresh acid and mention that on the statement itself. The example which he had given in the paper was 100 kilos of sludge = 80 kilos of fresh.

Any question of by-products was difficult. If there was genuine waste steam he would not value it. He thought that was the simplest principle: anything which was a genuine by-product should not be valued.

Reference had been made to the case of mixing up process costs and plant costs, but there really was no question of that. What he meant was that if the operating expenditure on a plant could not be divided quite naturally, without allocation of any sort, over two products there should be only one statement. If, on the other hand, without any forcing, separate figures could be got out for two products, then by all means the costs for the products should be given. In the usual case, however, at any rate in his experience, any attempt to give costs by type of output was almost certain to fail, because what one described as the cost of each type was not really so; it was the result of the expenditure on one operation being subjected to a forced allocation between the products, and, if that forced allocation was put through, then he believed that the costs to a large extent lost their value and ceased to be a safe guide to people who required them as a guide to operating efficiency.

The criticism had been advanced that one charge should be made to each process for the services rendered by each auxiliary, such charge to include direct expenses, fixed charges and depreciation, rather than to show each of these separately on the cost statement. In recommending that the distinction should be maintained on the cost statements, the purpose had been to present the figure in a suitable form for considering the possible effect of changes in operating methods, for example, whilst saving might be achieved in the direct costs of an auxiliary as a result of a change in operating practice, the same possibilities did not exist in the case of overheads and depreciation. The cost statements should, therefore, draw attention to the variable elements in the expenditure by keeping these entirely separate from the overhead and depreciation figures which were fixed in the sense that they varied little, or not at all, with the activity of the particular process.

A CONTRIBUTION TO THE STUDY OF "PINKING." *

By J. K. Thompson and R. V. Wheeler.

In previous papers, Maxwell and Wheeler [1] have described flame-photographs characteristic of "pinking" and "non-pinking" explosions obtained on igniting various mixtures, more particularly pentane and air and benzene and air, at one end of a cylinder under different initial conditions of temperature and pressure. With pinking explosions, which were always audible, there was but little luminosity in the products of combustion behind the flame-front, but a sudden and intense glow occurred throughout the cylinder at the moment when the flame-front reached the end remote from the point of ignition. This after-glow synchronized with an abrupt development of pressure. With non-pinking explosions, which were inaudible, the photographs showed smoothly continuous illumination behind the flame-front, and the development of pressure was continuous.

The cylinder used for the experiments during which these observations were made was not strong enough to allow of initial pressures much higher than 4 atm. being used. A stronger cylinder was therefore constructed, to enable the effects of higher initial pressures to be studied.

The combustion-space of the new cylinder was of the same dimensions as for the old, namely 15 in. long and of 6 in. diameter. It was made from a massive forging of nickel steel, the ends being closed by heavy circular covers bolted on with lead washers at the joints. Photographs of the flames of the explosions could be obtained through a row of circular windows along the side of the cylinder. Each of the windows was a truncated cone of optical glass of minimum diameter 11 mm., and was fitted into the side of the cylinder from within, with the end of larger diameter flush with the inner wall. A sparking plug at the centre of one of the end-covers provided means of ignition, and through a gland in the same cover a spindle carrying a small fan passed. This fan could be used either for mixing the charge or for rendering it turbulent during an explosion; when not in use, the fan could be drawn back into a slot in the cover. The cover at the other end of the cylinder carried, centrally and flush with its inner surface, the diaphragm of an optical manometer and a valve, for introducing the explosive mixtures, the spindle of which ended flush with the inner wall of the cylinder when the valve was completely closed. During an explosion, the walls of the cylinder were free from any projections or pockets which might influence the movement of flame. The cylinder was mounted horizontally and immersed in an oil-bath heated by submerged electrical resistances.

The flame of an explosion was photographed on a revolving drum covered with sensitized paper, which also received a continuous pressure record,

* Paper received June 5th, 1935.

the image of an electric spark (at an external spark-gap) that was passed at the moment of ignition of the mixture, and the trace of an electrically-maintained tuning-fork of 100 frequency.

This apparatus has been used to study, in particular, the behaviour on explosion of a range of mixtures of pentane and air, with initial pressures up to 9 atm. and initial temperatures up to 100° C. Explosions of other fuels have also been studied.

Explosions of Pentane and Air.

A record obtained on explosion of a 3 per cent. pentane-air mixture, initially at 4 atm. and 15° C., a typical pinking explosion, is reproduced on Plate I, Fig. 1. A diagram of the explosion-cylinder, with its series of windows, is shown at the top of the photograph. The flame moved at a slowly increasing speed from the point of ignition (on the right in the photograph) until it had traversed about two-thirds the length of the cylinder. Its speed was then checked, consequent on the flame-front spreading over the whole cross-section of the cylinder and being cooled by contact with the wall.[2] Thereafter, the flame moved steadily and more slowly to the end of the cylinder. Illumination behind the flame-front was not intense until inflammation was completed, but at that moment there was a sudden increase in luminosity throughout the combustion-space. One centisecond before the flame reached the end of the cylinder, the manometer registered a pressure of 15 atm. Coincident with the sudden increase in luminosity of the flame, the pressure rose rapidly to 30 atm. It is thus evident that the major proportion of the energy of a pinking explosion is released during the final stage of propagation of flame through the mixture.

The Effect of Initial Pressure.—Pinking explosions were obtained from mixtures of pentane and air containing not less than 3·0 per cent. of pentane when the initial pressure was 4 atm. When the initial pressure was increased, it was found that weaker mixtures gave pinking explosions. This effect of the initial pressure is illustrated by the records reproduced on Plate I, Figs. 2 and 3. For Fig. 2, the mixture contained 2·76 per cent. of pentane and the initial pressure was 3 atm. (initial temperature 15° C.). The record is typical of a non-pinking explosion: there is continuous illumination behind the flame-front, no increase in luminosity at the moment of completion of inflammation, and a steady rise of pressure to a maximum reached after complete inflammation. For Fig. 3, the initial pressure was 6 atm. (initial temperature 15° C.) and the mixture contained 2·87 per cent. of pentane. The record has all the characteristics of a pinking explosion, the sudden increase in luminosity and coincident sudden rise in pressure being marked.

The progressive effect of increased initial pressure in reducing the concentration of pentane which would provide a pinking explosion is shown by the following determinations, all of which were for mixtures at an initial temperature of 15° C.:

Initial pressure, atm.	2	3	4	5	6	7	8	9
Minimum concentration of pentane for pinking explosion, per cent.	3·2	2·95	2·85	2·75	2·70	2·65	2·60	2·60

FIG. 3.

FIG. 2.

FIG. 1.

[*To face p.* 932.

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

PLATE II.

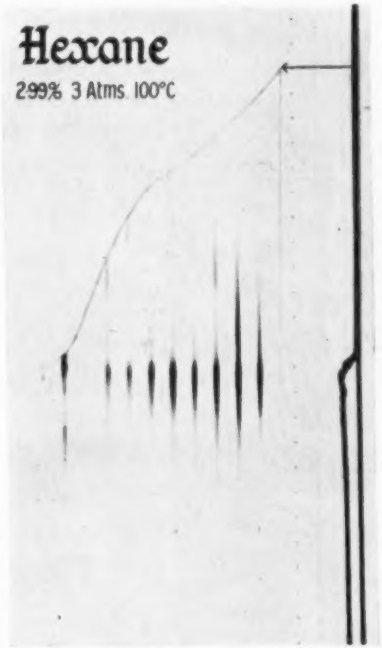


FIG. 8.

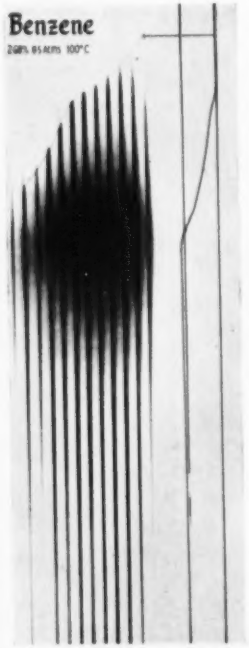


FIG. 9.

FIG. 10.

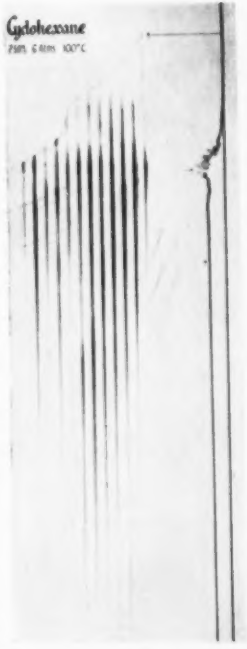


FIG. 11.

PLATE III.

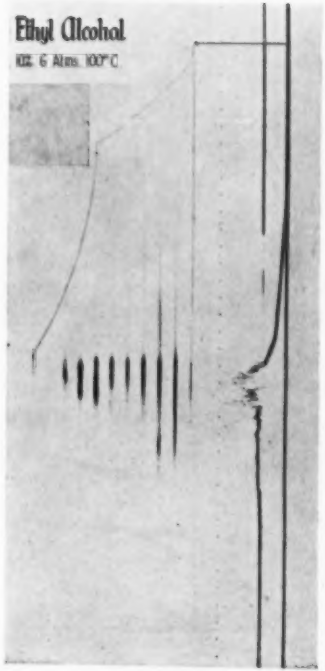


FIG. 12.

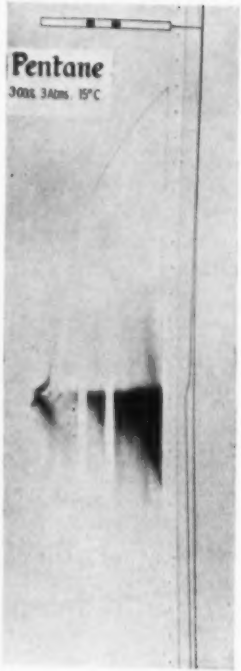
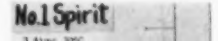
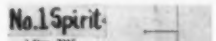


FIG. 13.

FIG. 14.

FIG. 15.





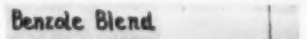


FIG. 12. FIG. 13. FIG. 14. FIG. 15.

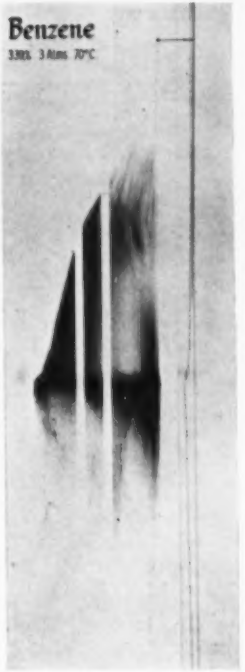


FIG. 16.

FIG. 17.

FIG. 18.

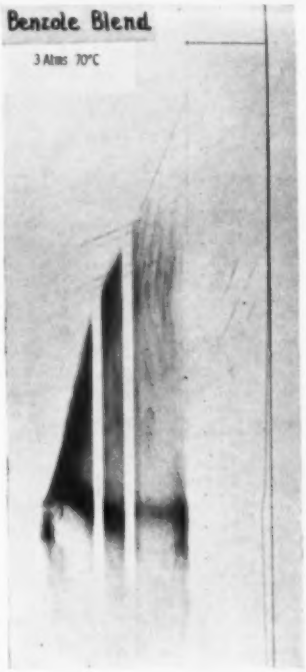


FIG. 19.

PLATE V.

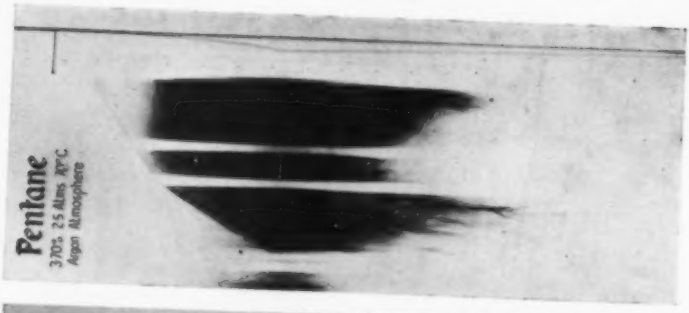


FIG. 23.

FIG. 22.

FIG. 21.

FIG. 20.

With mixtures containing less than 2·6 per cent. of pentane the flame photographs always showed continuous illumination behind the flame-front. At the highest initial pressures, pinking explosions were given by mixtures containing but little more pentane than is required for complete combustion by air (2·55 per cent.). It was noticed that as the initial pressure was increased the pitch of the sound produced by a pinking explosion rose, but the appearance of the flame-photographs, apart from a slight reduction in the speed of the flame, did not alter.

The Effect of Initial Temperature.—Series of experiments were made in which the initial temperature was raised to 50° and 100° C., the initial pressure being increased to maintain the same density of charge as at 15° C. With an initial temperature of 50° C. the photographic records of pinking explosions did not alter in appearance, but with the initial temperature 100° C., and high initial pressures, the track of the flame-front could barely be discerned. Fig. 4 (Plate II) is a record obtained from 3·34 per cent. pentane–air, initially at 8 atm. and 100° C. (equivalent in density to 6 atm. at 15° C.).*

At low initial pressures, the effect of increased initial temperature was slightly to reduce the concentration of pentane required to produce a pinking explosion, but with densities of charge equivalent to more than 5 atm. at 15° C. this effect was negligible.

A pinking explosion of pentane and air can thus be obtained, with suitable initial temperatures and pressures, with mixtures containing more than the theoretical amount of pentane for complete combustion, but not with mixtures containing less pentane. This observation supports the view that the source of the energy of the shock-wave responsible for the pinking lies in the partly-burned gases behind the flame-front. Further support for this view is given by the records reproduced in Figs. 5 and 6. Fig. 5 was obtained from 3 per cent. pentane–air initially at 4 atm. and 50° C., and is of the normal pinking type. For Fig. 6 the mixture contained the same concentration of pentane but some of the nitrogen in the air had been replaced by just sufficient oxygen to ensure complete combustion. Although the speed of the flame was considerably faster than in the pentane–air explosion, the explosion was non-pinking, the illumination was continuous and the pressure-record was smooth.

An essential condition for a pinking explosion of pentane and air therefore appears to be an excess of pentane.

The Effect of Turbulence.—In the experiments made by Maxwell and Wheeler (*loc. cit.*) with low initial pressure, pinking during an explosion of pentane and air could be suppressed by rendering the mixture turbulent. On attempting to suppress pinking in a 3·5 pentane–air mixture, initially at 7 atm. pressure, by running a fan at 2400 revs. per min. near the centre of the cylinder, a violent explosion giving a loud metallic clang was produced. A record of this explosion is reproduced on Plate II, Fig. 7. The manometer recorded a series of violent shocks and the combustion-space was re-illuminated between the point of ignition and the position of the fan. This suggested that the position and direction of rotation of the fan might influence the explosion, but changes in these did not affect the result.

* In the legends on the photographs, the initial pressures have throughout been expressed as equivalent pressures at 15° C.

On increasing the degree of turbulence, however, a pinking explosion was transformed into one that was but mildly vibratory.

A Comparison of Different Fuels.

Three fuels, *n*-hexane, benzene and *cyclo*hexane, were chosen as representing the six-carbon members of the groups of hydrocarbons commonly present in gasolene, for study of their explosion characteristics. Experiments were also made with ethyl alcohol and *n*-heptane, as having widely different pinking properties.

n-*Hexane*.—The records of explosions of *n*-hexane–air mixtures did not differ much from those of pentane–air under similar conditions. Fig. 8 (Plate III) is for a 2·99 per cent. mixture at an initial pressure of 3·3 atm. and 100° C. As with pentane–air mixtures, increased initial pressures up to the equivalent of 5 atm. at 15° C. did not modify the character of the flames of the explosions, but enabled pinking explosions to be obtained with lower concentrations of fuel.

Benzene.—Explosions of benzene–air are characterized by intense and long-continued combustion behind the flame-front. This characteristic persists with mixtures containing but little excess fuel up to initial pressure of 11·1 atm. at 100° C., as is shown by Fig. 9 (2·68 per cent. benzene). The illumination follows immediately behind the flame-front and lasts during 0·5 sec., whilst the pressure rises steadily and reaches a maximum after inflammation is complete. With richer mixtures, under the same conditions of initial temperature and pressure, vigorous shock-waves might be produced during the explosions. In Fig. 10, for example, for a mixture containing 3·7 per cent. benzene, it will be seen that the flame accelerated as it approached the end of the cylinder, and that there was then increased illumination throughout the combustion space, coincident with a violent shock recorded by the manometer. In these respects the record resembles those of explosions of rich pentane–air mixtures, but there is still the continuous glow behind the flame-front characteristic of benzene–air explosions. The mean speed of flame is rather faster in benzene–air mixtures than in equivalent mixtures of pentane–air or hexane–air.

cyclo*Hexane*.—The records obtained with *cyclo*hexane were similar to those with benzene, but with an initial pressure of 7·8 atm. at 100° C. explosions of mixtures containing about 10 per cent. excess of fuel produced violent shocks (see Fig. 11). *cyclo*Hexane is thus intermediate in character between benzene and the paraffins, inasmuch as, whilst the records of explosions show a continuous glow behind the flame-front, vigorous shock-waves can be set up in comparatively weak mixtures. As with pentane and *n*-hexane, the initial pressure required to enable a pinking explosion to be obtained from a mixture approaching that for complete combustion was fairly definite (about 8 atm. at 100° C.).

n-*Heptane*.—Pinking explosions with mixtures of *n*-heptane and air gave similar records to those obtained with the other paraffins, save that the luminosity of the flames was lower and less excess of fuel was required. Thus, a mixture containing 1·93 per cent. of *n*-heptane (theoretical mixture for complete combustion, 1·88 per cent.) gave a pinking explosion when the initial pressure was 4·4 atm. at 100° C.

Ethyl Alcohol.—Non-pinking explosions were obtained with mixtures containing up to 20 per cent. excess of ethyl alcohol, and the records were similar in appearance to those obtained with benzene. A pinking explosion could, however, be obtained with a very rich mixture at a high initial temperature and pressure (see Fig. 12, Plate IV).

These experiments show, in general, that the effects observed with different fuels when the initial pressures were low are not materially modified when pressures considerably higher than obtain in normal engine practice are used. During the explosions, pressures exceeding 70 atm. were frequently recorded.

An important observation is the reduction in the concentration of fuel with which a pinking explosion can be obtained, by increasing the initial pressure. Measurement of the lowest initial pressure with which a mixture containing nearly the theoretical quantity of fuel for complete combustion would produce a pinking explosion should afford a measure of the "anti-knock" value of the fuel. A comparison is made in Table I of these values, as determined for the different fuels tested, with the H.U.C.R. and the octane numbers as determined in a Ricardo E 5 engine at the Anglo-Iranian Oil Company's Research Laboratories.

TABLE I.

The Anti-knock Values of Fuels.

Fuel.	Initial Pressure for Pinking Explosion, lb. per sq. in.	H.U.C.R.	Octane Number.
n-Heptane	50	3·32	0
n-Hexane	60	4·12	32
n-Pentane	80	5·22	67
*cyclo*Hexane	100	>7·85	>100
Benzene	>150	>7·85	>100

The correspondence between the values is reasonably close. This method of study can, however, only be applied conveniently to pure substances having a sufficiently high vapour-pressure at room temperature to enable analyses of the mixtures to be made.

A Study of Commercial Fuels

It having been found that the character of the flames produced on explosion of mixtures of air with different fuels was not materially altered by increase in the initial pressure of the mixtures, the research was continued with mixtures at low initial pressures. The original explosion-cylinder described by Maxwell and Wheeler (*loc. cit.*) was used, since this had a continuous window through which the flames could be photographed. A new electrical recording manometer capable of responding to rapid changes of pressure (see Safety in Mines Research Board Paper No. 91) was fitted to the cylinder.

Before testing a number of commercial fuels, records of characteristic explosions of pentane, hexane, *cyclo*hexane and benzene were obtained for comparison.

Pentane.—Fig. 13 is a record of a pinking explosion of 3·09 per cent. pentane–air initially at 3 atm. and 15° C. The pressure rose steadily until the moment at which the flame accelerated towards the end of the cylinder, when it increased rapidly, but showed no signs of vibration. When the concentration of pentane was increased above 3·2 per cent., vibrations appeared on the records of both flame and pressure, as shown in Fig. 14.

The striations on the flame photographs first appear at the moment when the flame begins its final acceleration, and simultaneously the pressure record shows vibrations which increase in amplitude as the flame approaches the end of the cylinder. When the combustion-space is suddenly re-illuminated, the manometer records several vigorous oscillations lasting during about $\frac{1}{2}$ centisecond; thereafter, the amplitude of the vibrations is considerably reduced, but they persist six centiseconds after the attainment of maximum pressure.

The frequency both of the flame striations and the pressure vibrations is identical, being 1200 per sec. during the period between their first appearance and the attainment of maximum pressure, and thereafter gradually falling to 1100 four centiseconds after complete inflammation. The dark bands of the flame striations (*i.e.* emissions of light) at the end of the cylinder carrying the manometer (*i.e.* at the top of the photograph as reproduced) correspond with the peaks of the pressure vibrations, whilst at the ignition end of the cylinder they correspond with the troughs. This suggests that a stationary wave has been set up in the cylinder, the nodes at either end of it being alternately regions of compression and rarefaction corresponding with the alternate dark and light bands of the striations.

A reduction in the length of the cylinder from 15 to 9 in. increased the frequency of the vibrations from 1200 to 2000, so that the frequency is inversely proportional to the length of the cylinder. Increasing the initial pressure of the mixture to 4 atm. did not alter the frequency of the vibrations, and they were not entirely removed when the mixture was rendered turbulent. It has been suggested by Souders and Brown [3] that the initial impetus that causes a pressure-wave to be set up is given by sparks which pass subsequent to that which causes ignition. When the pentane–air mixtures were ignited by a heated iron wire, however, the vibrations were still produced.

n-*Hexane.*—Pinking explosions of hexane–air resembled in all respects those of pentane–air, the frequency of the vibrations being also 1200. Similar results were obtained with *n*-heptane.

cyclo*Hexane.*—With *cyclo*hexane–air at an initial pressure of 3 atm. it was necessary to use rich mixtures in order to obtain explosions that produced stationary waves. With an initial presssure of 4 atm. the explosion of a 3·01 per cent. mixture showed striations (Fig. 15) of frequency 1200.

Benzene.—With 3 atm. initial pressure, no benzene–air mixture produced a stationary wave on explosion. Fig. 16, for 3·39 per cent. benzene, shows faint striations just before the final acceleration of the flame, and one vibration at the moment of maximum pressure, but there is no indication of a sustained pressure-wave.

For this series of fuels, therefore, the ease with which their explosions produced stationary waves afforded an index of their anti-knock value. Commercial fuels were now examined from this point of view. Nine samples were obtained locally, representing straight-run No. 1 spirit, commercial, benzole and ethyl blends.

The temperature of the explosion-cylinder during these experiments was maintained at 70° C., and the initial pressure of the mixtures was 3 atm. A mixture of known composition was obtained by introducing a measured quantity of the liquid fuel into the evacuated explosion-vessel, allowing air to enter and running the fan rapidly. A range of mixtures could thus be obtained with each gasoline, and the transition between a non-pinking explosion and one in which marked striations appeared could readily be observed from the records. The concentration of gasoline required for the explosion to exhibit vibrations indicated the anti-knock value of the fuel.

But little difference could be observed amongst the four straight-run spirits as regards their tendency to produce "striated" explosion-flames. Figs. 17 and 18 (Plate V) are typical records which, it will be seen, resemble those for the pure paraffins. With the benzole blend (see Fig. 19), the high luminosity of the flame typical of benzene was evident, and the pressure records showed but slight vibrations. One gasoline (Fig. 20) appeared to have a high anti-knock value, for vibrations on the pressure records were scarcely perceptible. With the commercial spirit (Fig. 21) it was difficult to ensure complete vaporization of the fuel at 70° C., so that the composition of the mixtures was uncertain. When the ethyl blends were tested in the manner described, the explosions were similar to those of straight-run gasolines. As other investigators have shown, the anti-knock property of the lead tetraethyl did not become apparent unless the gasoline vapour was preheated (to about 300° C.) before passing it into the explosion-cylinder. Fig. 22 is of an explosion of a mixture prepared in that manner. Although there is a marked acceleration of the flame as it approaches the end of the cylinder, and a simultaneous rapid rise of pressure, there are no vibrations and the flame is highly luminous throughout.

The Effect of Diluent Gases.

During a study of the movement of flame in mixtures of carbon monoxide and air, Ellis and Wheeler [4] observed that the substitution of argon for the nitrogen greatly increased both the speed of propagation of the flame and its luminosity. Details of striated flames during pinking explosions might, therefore, more readily be studied if in pentane–air mixtures, for example, the nitrogen were replaced by argon.

On making such experiments, it was found that the character of the explosions had been completely altered. At an initial pressure of 3 atm. and 70° C., no mixture of pentane and air gave a pinking explosion. Fig. 23 is a record for 3·7 per cent. pentane, and should be compared with Fig. 14. The explosion was silent. The mean speed of the flame is twice that of the corresponding pentane–air mixture, and the maximum pressure developed is considerably higher. With some of the mixtures slight vibrations of pressure were recorded, but the maximum pressure was always

attained after the flame had reached the end of the cylinder, and the illumination behind the flame-front was always continuous.

A series of experiments was now made to determine the effect of progressive substitution of the nitrogen in air by argon. All the experiments were made with 3·2 per cent. pentane at an initial pressure of 3 atm. and 20° C. The results are recorded in Table II.

TABLE II.

Explosions of Pentane with Nitrogen–Argon–Oxygen.

Nitrogen and Argon (Proportions in Inert gas.)		Indications of Pinking.	Vibrations.	Time from Ignition to Maximum Pressure. Centisecs.
Nitrogen.	Argon.			
100	0	Positive	Positive	14·5
75	25	,,	Negative	9·5
50	50	,,	,,	8·1
40	60	Slight	,,	8·0
30	70	Negative	,,	7·4
20	80	,,	Slight	6·0
10	90	,,	Positive	5·8
5	95	,,	,,	5·7
0	100	,,	,,	5·6

A pinking explosion ceased to be obtained when the proportion of nitrogen in the inert gas fell below 40 per cent., but the flames exhibited striæ (and the pressure records corresponding vibrations) when the inert gas was either nitrogen alone, argon alone or contained up to 20 per cent. of nitrogen. The vibrations observed when argon was the inert gas were of considerably less amplitude than in a pinking explosion, but had the same frequency.

An explosion of 3·5 per cent. pentane with an atmosphere containing 21 per cent. oxygen and 79 per cent. helium (at an initial pressure of 3 atm. and 70° C.) was non-pinking, and the flame-photograph showed intense and continuous illumination without any trace of striation. Explosions of pentane with oxygen and carbon dioxide (replacing the nitrogen of air) were slow and silent, and the flames were almost non-actinic. The specific heats of helium, argon, nitrogen and carbon dioxide at constant volume are 3·0, 3·0, 6·22 and 11·5 cals. per mol. at 2000° C. The different effects observed with these gases as diluents during the combustion of mixtures of pentane and oxygen cannot be purely thermal, for, as compared with nitrogen, helium and argon would raise the temperature and pressure of the explosions and carbon dioxide would lower them, and it can be concluded that, in a normal pinking explosion, the nitrogen is playing an active part.

As an active agent in a pinking explosion, nitrogen could either form oxides or could absorb energy. If its action were due to the formation of oxides, one might expect to be able to remove the oxides as soon as formed by introducing traces of substances such as pinene or ammonia, which would react directly with them, or methyl iodide or carbon disulphide, which, by their oxidation in the flame-front, would yield products that would

react. In tests with each of these substances, however, in concentrations up to 1 per cent. of the volume of the fuel (pentane), the character of the explosions was not appreciably affected.

Conclusions.

A study of explosions of motor fuels in closed cylinders, whereby records of the development of pressure and the movement of flame can be obtained, affords information as to the difference in behaviour between "pinking" and "non-pinking" fuels.

The major proportion of the energy of a pinking explosion is released suddenly, just before the flame completes its path in the cylinder.

For a mixture of a fuel with air to produce a pinking explosion, it is essential that the fuel should be in excess of that required for complete combustion; and the concentration of fuel required to provide a pinking explosion increases as the initial pressure is lowered. A measure of the "anti-knock" value of a fuel can be obtained from a determination of the lowest initial pressure (in "closed cylinder" experiments) with which a mixture containing nearly the theoretical quantity of fuel for complete combustion can produce a pinking explosion. Alternatively, with a constant initial pressure, the concentration of fuel required to produce an explosion the flame of which is striated affords a measure of its anti-knock value.

The character of a pinking explosion is completely changed if the nitrogen of the air is replaced by either argon or helium, all other conditions remaining the same. For example, whereas 3·7 per cent. pentane–air at an initial pressure of 3 atm. and 70° C. gives a strongly pinking explosion, an explosion of 3·7 per cent. pentane–oxygen–argon, at the same initial pressure and temperature, is silent, despite the fact that the speed of the flame is twice that in pentane–air; there is continuous (and intense) illumination behind the flame-front in the pentane–oxygen–argon explosion, and the pressure is developed regularly.

It would appear that during the later stages of flame propagation in a non-pinking pentane–oxygen–argon explosion there must be less residual energy than in the pinking pentane–oxygen–nitrogen explosion. The nitrogen, therefore, seems to play an active part in a pinking explosion, perhaps as an absorber of energy or perhaps as a producer of oxides.

The work described in this paper has been carried out for the Anglo-Iranian Oil Co., to whom the thanks of the authors are due for permission to publish the results.

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[1] *J.I.P.T.*, 1928, **14**, 175; 1929, **15**, 408.
[2] Ellis and Wheeler, *J.C.S.*, 1928, 3215.
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[4] *J.C.S.*, 1927, 310.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TRINIDAD BRANCH.

THE Forty-fourth General Meeting of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Apex Club, Fyzabad, on Wednesday, April 24th, 1935, Commdr. H. V. Lavington, R.N., Branch Chairman, in the chair.

The following paper was presented :—

NOTES ON THE GEOLOGY OF SOUTH TRINIDAD WITH SPECIAL REFERENCE TO PALO SECO

By G. W. HALSE (Member).

SYNOPSIS.

The Forest Sands and Cruse Sands, which produce practically all the oil in Trinidad, are described in detail, as occurring at Palo Seco. As a whole, the Forest Sands exhibit remarkably exaggerated lateral variation, and, in places, were laid down not only at different angles, but also in different directions at Palo Seco, *e.g.* the general dip and strike in the region are no guide to the dip and strike of those particular sands. Above and below those beds respectively are two parallel and similar sand-clay junctions, at the top of the Forest Sands and at the top of the Cruse sands, which are very constant over a large area in South Trinidad. These are considered to represent regional unconformities or disconformities.

Original steep angles of deposition of beds, rapid lateral variation and unconformities, together with superimposed faulting, make it necessary to exercise much caution in interpreting underground structure from surface evidence, as well as in correlating sands from well to well.

The preservation of oil in Trinidad is dependent on the protection of non-competent sediments by some rigid mass, whereby shattering of the beds and loss of their oil have been prevented. This protective influence has been afforded by the Siparia Syncline, which is a major tectonic unit extending right across South Trinidad, and which is, in a large measure, responsible for the bulk of the production of the island.

The purpose of the following remarks is to promote discussion. We are still so much in the dark concerning the exact nature of the stratigraphy and structure of South Trinidad that anything bearing on these subjects affords unlimited scope for discussion. It is thought that detailed work in Palo Seco provides an explanation of some geological events of much more than merely local importance. In the time available, completeness of treatment of the subject cannot be attempted, and much that should be said is necessarily omitted. It is hoped, however, that the description of a few special features of the Palo Seco structure may lead to an interchange of ideas which should advance the understanding of the vastly complex problem of the geology of South Trinidad.

THE OIL-BEARING ROCKS OF PALO SECO (MIOCENE).

As the Oil Series of Trinidad has already been sufficiently described for the purpose of these notes, it is only necessary to give a brief account of

the points of particular interest or relevance to the subject under discussion. Thicknesses given are as found in Palo Seco by drilling.

Top Cruse.—Only the top 400 ft. of this group are considered here. This is the main oil-bearing horizon of Palo Seco. It consists of sands with interbedded clays. Cores show these sands to be generally much steeper and more irregularly dipping than the overlying clay group, and frequently to exhibit evidence of crushing. Occasionally they contain sandstone pebbles and fragments of rock which is of the same general aspect as the matrix, and have the appearance of being both conglomeratic and brecciated. Sandstone dykes are quite frequent. Thus these beds, while partly conglomeratic in origin, give the impression of having been subjected, since their deposition, to more disturbance than simple regional folding.

Intermediate Clay (100 to 400 ft. thick).—Resting on the Top Cruse is the so-called Intermediate Clay. Sometimes the change from the Cruse Sands to the overlying Clay is abrupt, and sometimes there is a silty phase up to 30 or 40 ft. thick intervening at Palo Seco.

This Clay gives a remarkably distinctive Schlumberger diagram. Its resistivity is exceptionally low, and its porosity is rather high for a shale. This may be connected with slicken-siding, but the evidence is not conclusive. It can be recognized clearly on 85 per cent. of the Palo Seco electric logs. Its thickness generally ranges between 50 and 180 ft., above which sands become frequent.

Forest Sands (900 to 1200 ft. thick).—The Forest Sands commence anywhere from 50 ft. upwards from the base of the Intermediate Clay. An interesting point about them is that their dip may differ considerably, both in amount and direction, from that of the general structure in the vicinity. In some localities, Schlumberger correlation shows that these sands dip at a much steeper angle than the overlying Forest Clay, and that they are frequently very lenticular. About one quarter of the total oil production of Palo Seco to date has been obtained from these sands.

Forest Clay (*Cyclammina Clay*) (60 to 400 ft. thick).—There is almost invariably in Palo Seco a clean break from the Forest Sands to the overlying Clay. This key horizon is cored for in every well, and is easily recognizable. It forms a good marker on the electric log also, although there are occasional exceptions to this. The Forest Clay, which is indistinguishable in the hand specimen from the Intermediate Clay, is characteristically pure clay at the base, then the interbedding of silts and sands with the Clay commences. This sandy facies comes on at varying heights above the base of the Clay, but so far there has not been one known instance in Palo Seco of the lowest part of the Forest Clay being absent. It is invariably present.

In quite a number of wells in Palo Seco, Mud Flow derived from beds 3000 ft. or more below has been found interbedded in the Forest Clay. It varies from 1 ft. to 64 ft. in thickness, and does not occur at any fixed horizon, having been found anywhere from the base of the Clay to 80 ft. above the base. As practically no coring has been carried out higher than this, there has been no means of ascertaining either whether Mud Flow occurs higher, or whether it may have thicknesses in excess of 64 ft. This Mud Flow is also found in the outcropping Clay to the South. The

manner of its occurrence leaves little doubt that it was formed by sub-aqueous eruptions during the deposition of the Forest Clay.

The Lower and Upper Moruga Formation (5000 ft. thick).—The Forest Clay merges gradually upwards into the sands and silts of the Lower Morugas. In Palo Seco shallow wells have been drilled where this formation contains sands about 200 ft. thick near the surface, and a good supply of fresh water is obtained from them.

The Upper Morugas are still more sandy, and contain, in places, lignites and the porcellanites or naturally burnt clays which are so largely used for road metal and other purposes.

Some Characteristics of Palo Seco.

The accompanying section shows some of the special conditions met with at Palo Seco. In reaching conclusions from such variable conditions as exist here, it is by no means easy to be sure of adopting a balanced view. There is every opportunity of finding evidence which will fit in with different stratigraphic or structural interpretations.

The correlation of individual Cruse sands from well to well at Palo Seco has not yet been satisfactorily accomplished. At the same time, the Schlumberger diagram of the top oil sand appears very similar from well to well in two separate localities, and is suggestive of correlation. The fact, however, that cores so frequently show dips of 45–60° in the sands and interbedded clays proves the presence of some abnormal condition.

The dips of the Cruse Sands and Clays are too steep to be accounted for either by folding or steep angles of deposition, although both probably contributed towards this steepness. In addition to that, minute faults and flow structure in cores indicate differential adjustment within the strata. The unfailing occurrence of a pure marine clay resting directly on top of this sand assortment is very noteworthy. It is the same high up on the folds or down the flanks. It is a general, and not only a local condition. In the author's opinion, this change can only be explained by slight unconformity at the top of the Cruse in Palo Seco.

The interval between the Base of the Forest Clay and the top of the Cruse at Palo Seco varies between 950 and 1170 ft. The unevennesses are mostly in the Intermediate Clay, but they do not take place so rapidly as to prevent the top of the Cruse oil being forecast with tolerable accuracy. This unevenness suggests that there was slight warping while the Forest Sands were being deposited.

The general parallelism and continuity of both the Intermediate Clay and the Forest Clay with the constant interval of approximately 1000 ft. between them are a feature of most of the oilfield region of South-West Trinidad, and it is of great significance. It means that from Intermediate Clay to Forest Clay times was a period of comparative quiescence, during which about 1500 ft. of beds were deposited. The principal movement during this time was epeirogenic. If there was any folding, it can only have been on a very minor scale. It commenced with general subsidence, which caused the deposition of the Intermediate Clay, and subsequently similar subsidence allowed the deposition of the Forest Clay.

Within this period of quiescence, the Forest Sands were deposited.

Their chief characteristic is rapid lateral variation. There is no such thing as a continuous clay in these beds. This different type of sedimentation is in marked contrast to the Intermediate Clay below and the Forest Clay above.

When drilling first commenced in Palo Seco, the Forest Sands were thought to exhibit extreme lenticularity, so much so that correlation was almost impossible. The subsequent discovery, already mentioned, that these sands act as entirely independent bodies in regard to both the amount and the direction of their dip considerably modified previous views. It followed that correlations made parallel to the general dip are liable to be entirely misleading. Individual sands can now be traced from well to well, and a true correlation can be worked out.

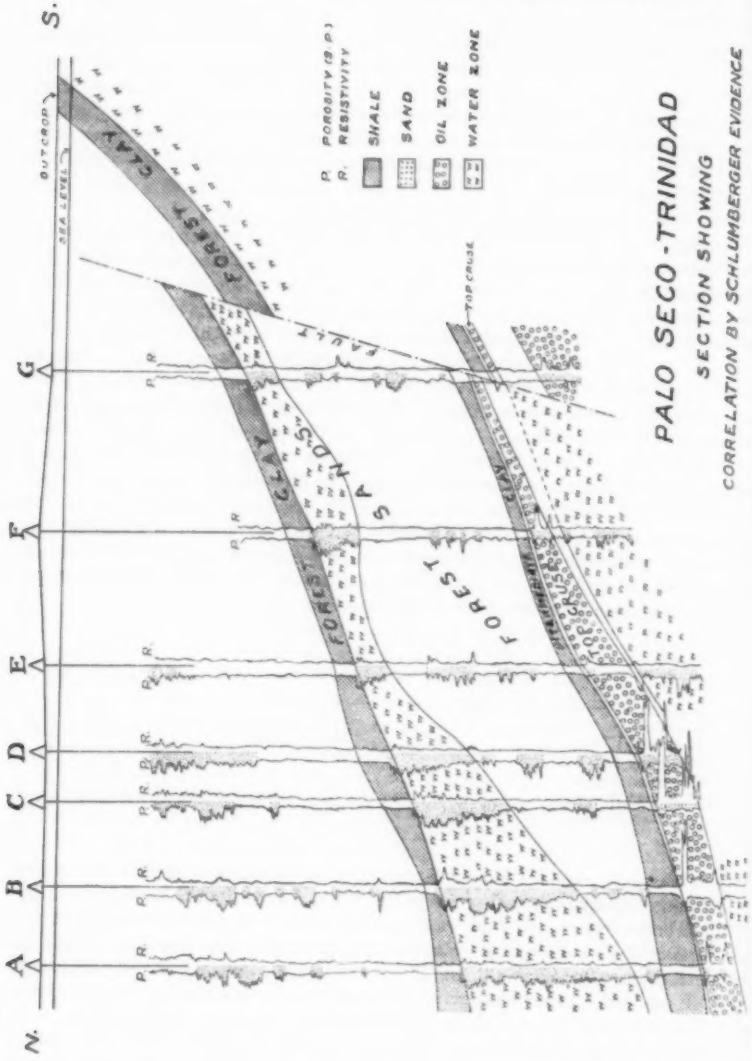
The figures in the following table are derived from a group of seventeen contiguous wells in Eastern Palo Seco. It will be noticed that, while the Intermediate Clay and Forest Clay are parallel, dipping at about 20°, the sands between them dip at angles from 31° to 40°. When the clays were horizontal, therefore, the Forest Sands were lying at an angle of 11–20°, which must have been their original angle of deposition. Furthermore, the direction of dip of the Forest Clay and the Intermediate Clay is almost the same, whereas that of the intervening Forest Sands diverges as much as 40° in direction from them. Although evidence suggests that there has been some differential movement along bedding, the rapid variations, both in the amount of dip and the direction of dip of the Forest Sands, relative to the two clays, leave no reasonable doubt that these discrepancies are mainly depositional. If this is a correct interpretation, it is highly probable that, in localities where the dip of the Forest Clay does not exceed 15° or 20°, some Forest Sands will be found which are horizontal or dip in the opposite direction to the true dip.

Horizon.		Angle of Dip.	Direction of Dip.
Moruga Sands (at Surface)	Unconformity	30°	N. 15° W.
Base of Forest Clay	Disconformity	21°	N. 35° W.
Base of Forest Sand A		40°	N. 52° W.
Base of Forest Sand C		34°	N. 67° W.
Base of Forest Sand D		31°	N. 48° W.
Base of Intermediate Clay or Top of Cruse	Unconformity	20°	N. 25° W.

The change from the Forest Sands to the overlying Forest Clay marks a horizon of great practical importance. The Forest Sands deposited under Deltaic conditions, with their rapid lateral variation and their steep angles of deposition which are so clearly illustrated in the Section, suddenly become a pure marine clay over a considerable area of South Trinidad. This sharp and general change in sedimentation can only be accounted for satisfactorily by a general and simultaneous change of conditions. It appears to be an almost exact repetition of the change at the top of the Cruse, except that the disturbance in the Forest Sands is of a lesser order than that in the Cruse Sands. In this case, therefore, the change may be one of disconformity only.

The fact that outpourings of Mud Flow occurred during the deposition

of the Forest Clay, indicates that there was movement of some kind at that time which caused lines of weakness in the earth's crust through



which the mud escaped at surface. Possibly this was the first phase of the main folding movement during late Pliocene or early Pleistocene times.

By correlation of a number of wells, as also by field mapping, it has been

found that the Lower Moruga beds cannot be relied on for interpreting underground structure in detail. In Palo Seco not only do they almost always dip at a steeper angle than the underlying Forest Clay, but their strike is not necessarily a guide to the underground strike, as shown in the table above. Even more misleading than this is the fact that at times sands in the Morugas dip in the opposite direction to that of the general dip of the underlying beds in the locality. On the other hand, Moruga sands may be found which are parallel to the Forest Clay over fairly wide areas. Instances of all these cases have been revealed by well correlation. In Eastern Palo Seco the Forest Clay in wells starts to swing round in an even curve towards the syncline to the north, but the Moruga beds at surface continue straight along, showing no indication whatever of this uniform and progressive change of strike in underlying beds. These facts afford conclusive proof of unconformity within the Lower Morugas (possibly about 1500 ft. above the base of the Forest Clay), together with variable local conditions of deposition above, such as infilling from different directions.

Structure.

The Palo Seco oilfield is situated down the north flank of the Southern Anticline about 2 miles from the crest. Actually it is perhaps more correct to say that it is situated in the syncline. Early development proved that better production was obtained by drilling towards the north, under protection of the syncline, rather than southwards towards the anticlinal crest. The accompanying section supports the argument that the main reason for this is a series of minor thrusts which shattered the oilsands in the crestal region and allowed much of the oil to escape. It is impossible to fit in surface and well evidence without these thrusts. Going down dip, when the Forest Clay is buried to a depth of about 1000 ft., these thrusts die out. Continuing down the flank from this point, dips are generally flatter than correlation lines, which suggests that normal faulting commences in the form of a number of strike faults of small throw. This agrees very well with the general conception that when strong folding has spent itself it is succeeded by settlement of the orogen, this settlement being characterized by normal faulting. It is highly probable that minor normal faulting is prevalent in the whole of Palo Seco, but it is very difficult to prove it directly. It might be an important factor in accounting for the wide difference in production from the same sand, and for the presence of oil in some cases and water in others at the same horizon in neighbouring wells.

The largest and most stable tectonic unit in South Trinidad is the Siparia Syncline. It stretches for over 50 miles from Cedros to Mayaro, its trend being E.S.E. in the Cedros–Point Fortin region, but the rest of it conforming to the general E.N.E. trend of South Trinidad.

The preservation of the Palo Seco oilfield is undoubtedly due to the protective influence of the Siparia Syncline, which has prevented the shattering of the underlying and adjoining beds. Similarly, the oilfields of Point Fortin, Parrylands, Fyzabad (Leaseholds, Apex and others) and Barrackpore have been preserved by it. It may be said, therefore, that most of the oil production of Trinidad is due, tectonically, to the protection of

this syncline. There is reason to hope that the number of oilfields to the credit of this syncline is not yet complete.

The author wishes to express his indebtedness to the Trinidad Petroleum Development Company for permission to publish details of their Palo Seco field, and to Mr. C. C. Wilson for helpful criticism.

DISCUSSION.

Mr. G. H. Scott said there was one point about the Top Cruse that he had to mention. Mr. Halse stated that there were signs of differential movement between that and the Intermediate Clay. In the Apex Field they got very similar conditions, but he did not think they pointed to any great unconformity between the overlying Intermediate Clay and the Cruse. They had accumulated much evidence in continuously cored wells, and it always seemed to him that the intensive folding in the Cruse was confined to its uppermost layers.

The sandstone dykes and brecciated clays that were mentioned as occurring in the Cruse, also occurred with them, in the Forest Sand Group. They were not confined to the Cruse.

It always appeared to him, from examination of the cores in the Top Cruse, that the wrinkling was in the form of a flow structure induced while the beds were in a semi-consolidated state. At the end of the Cruse age there must have been considerable uplift, followed by rapid submergence. An exact replica of these movements is evidenced at the Forest Clay–Forest Sand junction. Studying the whole series even deep into the Cruse, there was extraordinary constancy of oscillation, as evinced by the mimicry of lithological characters in beds deposited at the equivalent time phase of oscillation. Thus there was exact correlation between Intermediate Clay and Forest Clay and Forest Sands with the Morugas.

With regard to the Intermediate Clay, the Author gave the series close limits of thickness. These were very much narrower than were found at Apex, where the limits were 0 to 900 ft. It was difficult to explain such enormous differences in the true Intermediate Clay, a clastic clay of the Forest Clay type. One could not put it down to structural factors, because the habits of the Forest Clay and the Top Cruse exactly as cited by Mr. Halse argued against any considerable movement in the intervening beds. Similarly it was difficult to postulate overthrusting or an intrusive origin. There was nothing to suggest anything more than disconformity at the top of Intermediate Clay, yet the very rapid changes in the thickness, in the absence of any evidence for a tectonic interpretation, point definitely to extraordinary conditions of deposition with close delimitation of the basins in which the clay deposition took place.

He would like to ask the Author if he could give any explanation for the constancy of the Forest Clay, not only in thickness, but also in a real extent, as compared with the violent changes in the Intermediate Clay the lithological characters of which were identical.

Finally, the Author gave instances where the dips of the Forest Clay and Cruse correlation varied from the dip in the Forest Sands. He had been working quite a bit on that lately, and he found that the Forest

Clay correlation obtained from Electrical Logs may be entirely different from the actual Forest Clay attitude as obtained from very detailed core and dip evidence. He found in some cases the exact converse of the case cited by the Author, in which the Forest Sands were dipping more steeply than the Forest Clay. He had clear evidence in many cases that what appeared from pure stratigraphical correlation as a regularly dipping flank was, if dip evidence was taken into account, actually dissected by minor dip and strike faults. These faults were extraordinarily hard to detect without close drilling, but they had a very profound effect on the accumulations of oil in the Forest Sands. There were variations in the oils, in reservoir pressures, and in the nature of the fluid, be it oil or water, from fault block to fault block, which could be explained in no other way than by transformational migration from the Cruse to the Upper Sands with lateral limitation of such migration by the fault planes.

He would like to ask the Author whether the localization of his Forest Sand production could not be explained by the system of block faulting as the speaker suggested. It was so striking in the Apex Field that it must have extended to others.

The only other point was that he noticed the Author had omitted any mention of the mother oil rock. He did not know if that was a deliberate omission, but he would like to ask him whether he had arrived at any conclusion as to the source rock of the oil.

Dr. H. G. Kugler said that it was only by comparison of definitely known details of underground conditions as experienced in different fields that production methods could be improved, or far-reaching deductions drawn, leading to the discovery of new deposits.

Dr. Kugler then referred to the rapid lateral changes observed in the oil-bearing formation of South Trinidad. Considering South Trinidad as being a part of the Tertiary Orinoco delta, it is appropriate to compare present-day conditions with those pertaining during Upper Tertiary times, when equivalents of the present silt and mud banks with the sandy infills of flow channels existed. Sediments like those known as Cruse, Intermediate or Forest clays may very well be compared with the present sediments of the Gulf of Paria, being products of periods of regional submergence.

More difficult is the explanation of the more than four thousand feet of uniformly deposited sands and silts of the Moruga beds as observed between Mayaro and Moruga. Only a steadily submerging shelf section of the sediment-producing " Guiana shield " could account for such conditions.

Greater interest in physiography and careful study of the processes which change the earth's surface and subaqueous floors will explain many intricate problems of geology.

Mr. J. L. Harris said that Mr. Scott's remarks about the rhythmic sequence of deposition were most important. There were at least three uniform clay depositions above the Top Cruse oilsands, *i.e.* the 900-ft. clay, the Forest Clay and the Intermediate Clay. Each of these clays overlaid a development of oilsand.

There seemed quite a probability that deeper clay depositions over

wide areas would ultimately be recognized below the Top Cruse oilsand. He was also in agreement with Mr. Scott's remarks regarding the remarkable variation in thickness of Intermediate Clay. He had not observed thicknesses much in excess of 700 ft. On the other hand, the clay was frequently very thin or altogether missing.

Regarding the development of the Top Cruse sand, electrical surveys gave very uniform profiles showing three peaks of accumulation.

Down flank in the sand there appeared to be an oil-water junction, but such a junction was not uniform in every part. Electrical surveys showed that wells (approximately the same distance down flank) might have all three peaks watered, all three peaks oil-bearing, No. 1 peak watered, No. 2 oil-bearing and No. 3 watered, or No. 1 oil-bearing and No. 2 and No. 3 watered.

Mr. Halse evidently found that the Top Cruse Sand was the most prolific producer in the southern anticline. At Forest the Shallow Sands between the base of the Forest Clay and the Top Cruse had produced well over 60 per cent. of the production to date, and the sands deeper than Shallow Cruse appeared to have definite commercial possibilities.

The Forest Clay, unlike the Intermediate Clay, was a very persistent and uniform deposition, ranging from about 15 ft. to 120 ft. thick. It had not been located in every well in the Forest Fields, and there seemed reason to expect that it was missing in certain limited areas due to faulting or local variation in deposition.

The discovery of well-preserved plant remains in the Forest Clay seemed an additional argument against deposition at depth of this well-known and widespread formation.

The variation in interval between Forest Clay base and Top Cruse was more marked at Forest, being from 900 to 1500 ft., while there seemed a most regular interval between base of Forest Clay and top of the Pitch Sand, *i.e.* 900 ft.

The occurrence of Mud Flow at the Forest seemed definitely after the formation of the present structure. It appeared to be intruded from the crest of the dome and to have flowed to the South Flank. Thus at the crest it was interbedded or above and adjacent to the outcropping Forest Clay, and on the flank might extend at its edge to points 1700–2000 ft. above Forest Clay base.

He was in complete agreement with Mr. Scott's assertion that the accumulations of oil in Southern Trinidad were governed by cross faulting. If this was so, it was an additional reason for depending on drilling rather than surface mapping for ultimate exploration purposes in Trinidad.

Regularity of oil accumulation, as might be inferred from uniformity of deposition demonstrated by the extent of the Forest and 900-ft. clays, was negatived by indications of disconformity shown by variation in the interval between base of Forest Clay and Top Cruse and the inconstant thickness of clays like the Intermediate Clay.

It seemed practically certain that all commercial accumulations of oil in Trinidad were migratory, and if this assumption was correct, cross faulting and allied phenomena explained the extreme irregularity of such accumulations.

Mr. G. A. Richards said that the Author mentioned that the interval between the Intermediate Clay and Top Cruse varied somewhat. He imagined it was highly probable that to a certain extent the variation might be depositional. It might also be due to a certain extent to over-thrusting, whereby beds were repeated, leading to an increase in the normal interval in some parts of the field and to normal faulting, whereby a certain amount of the beds was cut out and the normal interval was decreased in other parts.

The speaker had been doing a fair amount of surface work in the Cedros district, and, as far as surface evidence went, it seemed to him that Cedros was very similar in general structural principles to Palo Seco. There was certainly a good deal of over-thrusting. If one took a north–south line across the peninsula anywhere, one could point out evidence of at least three or four overthrusts. There was also very definite field evidence of cross-faulting, and for at least two periods of movements. In some cases the cross-faults were shifted by the thrusts, and in others the thrusts were shifted by the cross-faults. It seemed that there occurred first of all a period of thrusting, followed by a period of cross-faulting; that was followed by a period of comparative quiescence, during which erosion took place, at least in some parts. Then there was another period of thrusting, followed by another and final period of cross-faulting.

Conditions were perhaps a little more complicated than those at Palo Seco, but it seemed that the general structure was one of block-faulting, and presumably the accumulation of oil and gas would be governed by that block-faulting.

It seemed to the speaker that when one took into consideration the unconformities and the evidence of thrusting, detailed surface mapping was of very little use as a guide to the underground structure over any small area. If detailed mapping was to be any good at all, it must be carried out over a very large area, so that some idea of the general structural trends and possible underground extensions of these trends might be arrived at.

Mr. A. J. Ruthven Murray said it was of considerable interest to know that in the Fyzabad area something like 70 per cent. of the oil was won from the Forest Sands; because in the Parrylands–Guapo area, lying to the north, they found that the Forest Sands were mostly replaced by argillaceous deposits, and that very few beds of sand occurred except at the base of this series. The Forest Series here lies unconformably upon the Cruse Series, as instanced by the steep dips and not infrequent presence of Mud Flow as found in cores at this horizon: this in contrast to Mr. Halse's reference to Mud Flow in the Forest Clay of Palo Seco to the South.

When drawing contours both on Top Cruse and on Lower Cruse, it is found that quite a different set of directions is obtained in each case; this points to an unconformity in the neighbourhood of 1400 ft. below Top Cruse.

One other thing he would like to mention, which was based on remarks made by Dr. Kugler when discussing the geology of the Pitch Lake region, was that earth movement has been much more intense towards the north, that is around the Guapo region, than in the Fyzabad–Palo Seco region

to the South. This is apparent from the severe crushing of the beds in the former region, and accounts for the less uniform distribution of petroleum.

Mr. G. W. Halse, in reply, said he attached great importance to a factor mentioned or implied by Mr. Scott, Mr. Harris, Dr. Kugler and Mr. Richards, namely, the rhythmic nature of the earth movements, which resulted in cycles of similar types of deposition. The most impressive illustrations of those repeated cycles were, of course, the Cruse Sand–Intermediate Clay phase subsequently repeated as the Forest Sand–Forest Clay phase.

He felt that Mr. Scott's opinion that the disturbances in the top Cruse took place before the beds were consolidated contributed materially towards an understanding of their extraordinary condition. Doubtless it applied to the Forest Sands also in which he observed similar phenomena. Mr. Scott's statement, that there was uplift then submergence at the close of Cruse times, meant at least disconformity. That was important because the greater the amount of evidence for disconformity at that horizon, the more reliable it became as an approximation to a time horizon which was easily recognizable over a wide area.

The variations in the thickness of the Intermediate Clay from 0 to 900 ft. quoted by Mr. Scott were very much like those of the sand shown on the section accompanying this paper, which varied from 150 to 800 ft. thickness in a horizontal distance of 1500 ft. As Mr. Scott said, such exaggerated lateral variation pointed to extraordinary conditions of deposition.

With regard to the false impression which might be obtained if correlation were made from Schlumberger diagrams without core evidence, the Author said he was in agreement with Mr. Scott—in fact, in the paper he specifically stated that down the flank dips were generally flatter than correlation lines which suggested normal faulting, etc.

The speaker stated that he was much impressed with Mr. Scott's remarks about the effect of faulting on the accumulation of oil, and thought there could be no doubt that it was a major factor, but it was extraordinarily difficult to work out precisely cause and effect. He thought, however, that Mr. Scott was in a better position than almost anybody there to discuss that subject, and he thought they could not do better than accept his opinion. He agreed with Mr. Scott that the presence of oil in the Forest Sands of Palo Seco could be explained by faulting.

He stated that Mr. Harris' mention of a pitch sand 900 ft. above the Base of the Forest Clay meant that that sand was laid down parallel with the Clay. The only condition under which such parallelism could be attained over a considerable area was by both beds having been deposited horizontally. That contrasted strongly with neighbouring areas, where, at the horizon under consideration, the sands had been laid down at varying angles of deposition. That particular sand, therefore, represented a local cycle of uniform rate of subsidence.

Continuing, he said that Dr. Kugler suggested a key to many of the local problems by his analogy between the oil-bearing beds of Trinidad and the Orinoco Delta. Dr. Kugler's suggestion that a greater study of physiography would yield results was a very valuable one.

Mr. Ruthven Murray's evidence of unconformity at the top of the Cruse in the Kern area added support to what the Author considered to be accumulating evidence of regional unconformity at that horizon. The less convincing evidence of unconformity in more gently folded areas was to be expected. Unconformity must be better developed on axes of strong folding than on gentler fold lines or towards the contemporary basins.

The great value of study of evidence from different localities was that an understanding of general conditions often helped the solution of local problems. The need for that had been stated both by Dr. Kugler and Mr. Richards.

In conclusion, he stated that mention of the origin of Trinidad oil was omitted because it was too big a subject to be introduced into so brief a paper.

On the motion of the **Chairman**, a vote of thanks was accorded the Author, and to their Hosts, the President and Members of the Apex Club, for the use of the room.

POLYMERIZATION PRODUCTS OF NORMAL 2-PENTENE AT HIGH TEMPERATURE.*

By H. I. Waterman, J. J. Leendertse and J. de Hulster.

SYNOPSIS.

A partly cyclic polymerization product of normal 2-pentene, obtained with aluminium chloride as a catalyst at 0° C., was heated at 200°, 300° and 435° C. to study the influence:

(*a*) of nickel catalyst in the absence of hydrogen (under high nitrogen pressure),
(*b*) of hydrogen without a catalyst,
(*c*) of hydrogen with nickel catalyst.

In the cases (*a*) and (*b*) even a long period of heating *at 200° C.* did not change the polymerization product. Therefore it is probable that also in the analytical hydrogenation of the product at 200° C. (with nickel and hydrogen) there is no change of the molecular structure.

The experiment (*a*) and (*b*) carried out *at 300° C.* caused a destruction which resembled a depolymerization. However, the presence of both nickel and hydrogen (experiment *c*) protects the product against destruction (6 hours at 300° C.). The product of this hydrogenation (experiment *c*) was practically the same as the corresponding hydrogenation product obtained at 200° C.

At 435° C. in both experiments (*a*) and (*b*) an important destruction was observed. In the experiment with nickel and nitrogen (experiment *a*) the liquid product was strongly unsaturated and cyclic. In this experiment also an increase in the total amount of rings was observed. In the case of the experiment with hydrogen without a catalyst (experiment *b*) the *total* number of rings had not changed much. The liquid reaction products in both experiments (*a*) and (*b*) contained in their higher molecular fractions more rings per molecule than the raw material.

The object of this investigation was to obtain information regarding the stability of synthetic hydrocarbons obtained by polymerization. Later a comparison will be made with the corresponding products from natural mineral oils. In the experiments in which a destruction was obtained, the products of the reaction were examined. The cyclic character of the products was a special object of investigation.[1]

At the same time, it was desired to ascertain the maximal temperature which can be used for analytical hydrogenation of polymerization products of this nature, without changing the molecular structure.[1]

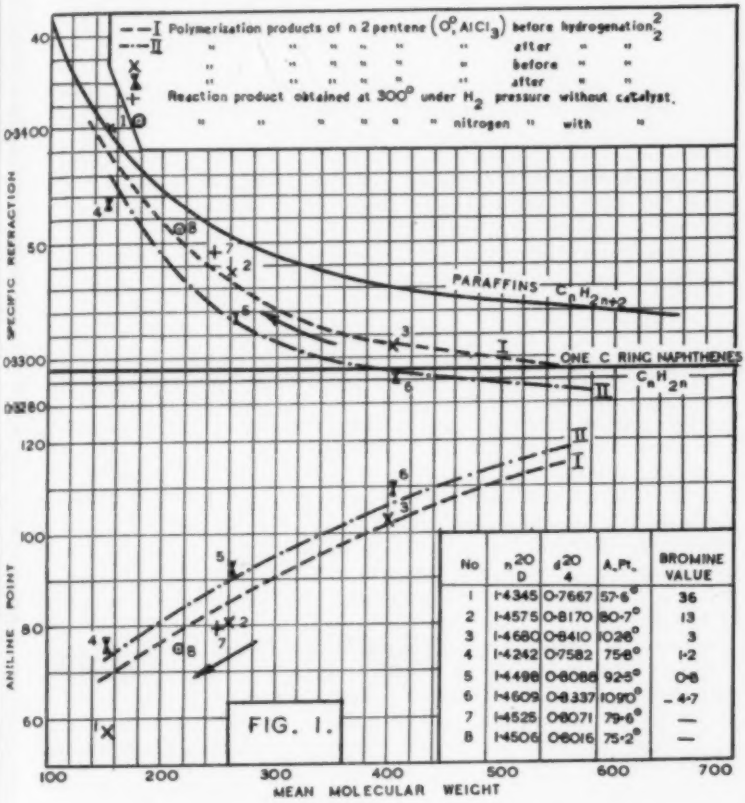
Raw Material.

The polymerization products used were prepared by polymerizing normal 2-pentene at about 0° C. with aluminium chloride as a catalyst. The normal 2-pentene was obtained by dehydrating 3-pentanol over aluminium oxide at high temperature. The details of the preparation of the 2-pentene and of the polymerization have been published.[2]

By distillation finally in cathodic light vacuum (with a maximal temperature of the liquid of 175° C.), the polymerization product was separated

* Paper received August 30th, 1935.

into three fractions: 1 (25 per cent. by weight of the total reaction product), 2 (25 per cent.) and 3 (50 per cent.). These fractions had a slightly cyclic character; the average number of rings per molecule was 0·25, 0·7 and 1·1, respectively. The chlorine percentage was small. The properties of the fractions 1, 2 and 3, and also the properties of the products obtained by careful hydrogenation of the fractions 1, 2, 3 (4, 5 and 6


I Polymerization products of n 2 pentene (0^0, $AlCl_3$) before hydrogenation
II " " " " " " after " "
" " " " " " before " "
" " " " " " after " "
Reaction product obtained at 300° under H_2 pressure without catalyst.
" " " " " " nitrogen " with "
SPECIFIC REFRACTION
ANILINE POINT
MEAN MOLECULAR WEIGHT
PARAFFINS C_nH_{2n+2}
ONE C RING NAPHTHENES C_nH_{2n}
FIG. 1.

No	n_D^{20}	d_4^{20}	A.Pt.	BROMINE VALUE
1	1·4345	0·7667	57·6°	36
2	1·4575	0·8170	80·7°	13
3	1·4680	0·8410	102·8°	3
4	1·4242	0·7582	75·8°	1·2
5	1·4498	0·8088	92·5°	0·6
6	1·4609	0·8337	109·0°	- 4·7
7	1·4525	0·8071	79·6°	—
8	1·4506	0·8016	75·2°	—

respectively) at 200° C. with nickel-on-kieselguhr as a catalyst are seen in Fig. 1. The specific refraction–molecular weight diagram, and also the aniline point–molecular weight diagram, show good agreement of the products 1, 2 and 3 with the polymerization products described in the previous communication,[2] and represented by the curves I in Fig. 1. The hydrogenation products (points 4, 5 and 6) are lying close to the curves II representing the corresponding products of the former experiments. In the specific refraction–molecular weight diagram the curves for the paraffins (C_nH_{2n+2}) and one-carbon ring-naphthenes (C_nH_{2n}) are also given.

Description of the Experiments.

Fraction 2 (see figure), with a mean molecular weight of 261, was heated at 200°, 300° and 435° C., respectively, under the following conditions:

(*a*) high nitrogen pressure (initial pressure 100 kg./cm.^{2} at room temperature *) in the presence of 10 per cent. of nickel-on-kieselguhr as a catalyst;
(*b*) high hydrogen pressure (initial pressure 100 kg./cm.^{2}, at room temperature *) without a catalyst;
(*c*) high hydrogen pressure (initial pressure 100 kg./cm.^{2}, at room temperature *) in the presence of 10 per cent. of nickel-on-kieselguhr as a catalyst.

All experiments with nickel as a catalyst were carried out in the same autoclave (content 130 ml.) under analogous conditions. The experiments without a catalyst were performed in a new autoclave of similar construction. The activity of the nickel catalyst was tested by a hydrogenation experiment with benzene.

Discussion of the Results.†

A. Experiments at 200° C. In the experiments with nickel as a catalyst under high hydrogen pressure at 200° C., the duration of heating at the reaction temperature was 1 and 6 hours, respectively. Even under these conditions the product practically did not change.

The experiment with hydrogen without a catalyst at 200° C. lasted 1 hour. Also in this case there was neither indication of a change in structure nor of hydrogenation. The experiment with nickel catalyst under high hydrogen pressure had been already carried out in the analytical hydrogenation of fraction 2 (point 2 in the figure, after hydrogenation, point 5). In this experiment the heating was continued for three periods of 1 hour each.

A survey of the properties of the products obtained is given in Table I.

From the experiments at 200° C. it may be concluded that nitrogen with nickel catalyst, or hydrogen without nickel, practically do not cause destruction or polymerization, isomerization or cyclization.

Therefore it might be said that also in the analytical hydrogenation of the product at 200° C. with nickel as a catalyst there is no change of molecular structure.

B. Experiments at 300° C. Whereas at 200° C. with hydrogen without a catalyst and with nitrogen with a nickel catalyst there is no change of the product, the temperature of 300° C. causes a destruction. Only a rapid hydrogenation by high-pressure hydrogen in the presence of a nickel catalyst can protect the polymerization product from destruction. This is proved by the physical constants of the reaction product obtained from fraction 2 with nickel and hydrogen at 300° C. (n_D^{20}, 1·4483; d_4^{20}, 0·8062;

* In the experiments at 435° C. a lower initial pressure was used.
† In all experiments the duration of the reaction is exclusive of the pre-heating period.

TABLE I.

Physical constants.	Raw material (fraction 2) before hydrogenation.	Fraction 2 after hydrogenation (hydrogen with nickel) 3 hours at 200° C.	Reaction product of		
			experiment with nitrogen and nickel 200° C., 1 hour.	experiment with nitrogen and nickel 200° C., 6 hours.	experiment with hydrogen without a catalyst 200° C., 1 hour.
$n_D^{15°}$	1·4575	1·4498	1·4575	1·4580	1·4579
$d_4^{15°}$	0·8170	0·8088	0·8170	0·8185	0·8167
$\frac{n^2-1}{n^2+2}\frac{1}{d}$	0·3337	0·3321	0·3337	0·3334	0·3340
Aniline point	80·7°	92·5°	81·0°	81·4°	80·6°
Bromine value	13	0·8	—	—	—
Mean molecular weight (C_5H_4)	261	265	262	260	263
Chlorine percentage	0·05	—	—	—	—
Average number of rings per molecule	0·7	0·7	0·7	—	—

$\frac{n^2-1}{n^2+2}\frac{1}{d} = 0{\cdot}3323$; aniline point, 91·5° C.; mean molecular weight, 260).

The differences of these constants from those of the hydrogenation product at 200° C. are small.

The properties of the products obtained in the experiment with hydrogen without catalyst, and with nitrogen with a nickel catalyst, are given in Fig. 1 (points 7 and 8 respectively).

It is seen from the average composition of the destruction products that they resemble depolymerization fractions. The figure indicates that the nature of the products of the destruction has a good resemblance with the nature of the corresponding products obtained by polymerization.[3] This is particularly the case with the product having a mean molecular weight of 215 (product 8).

The specific refraction and also the aniline point of the products 7 and 8 are practically equal to the same constants of a polymerization product of the corresponding molecular weight.

It may also be remarked that, notwithstanding the destruction, the velocity of the hydrogenation by high-pressure hydrogen at 300° C. without a catalyst is not sufficient to saturate the products of the depolymerization during their production.

From these experiments it may be concluded that the olefinic double binding is an easily-ruptured part of the molecule. The simultaneous presence of nickel and hydrogen rapidly saturates this double binding, and therefore in this case there is less danger of destruction. Evidently the saturated mixture of hydrocarbons is more stable to heating at 300° C. than the corresponding olefinic hydrocarbon mixture.

C. Experiments at 435° C. The destruction at 435° C. being very intensive, the duration of the experiments did not exceed 1 hour.

(a) *Experiment under high hydrogen pressure (initial pressure about*

80 *kg./cm.*^{2}), *without a catalyst, during* 1 *hour*. In this case a good deal of gas was formed. It was cooled by liquid air, and thus separated into a non-condensing part (A gas), chiefly hydrogen, and a condensate (B gas).

By weighing the autoclave, it was possible to determine the quantity of liquid reaction products obtained.

Before the experiment.		After the experiment.	
Raw material (fraction 2),	24·5 g.	Liquid product,	21 g.
Hydrogen	0·7 g.	A gas	1·2 g. (difference)
		B gas	3·0 g.
Total	25·2 g.	Total	25·2 g.

By distillation, the liquid was separated into a distillate (7 g.) and a residue (11·5 g.).

The analysis of the distillate indicated that an important part of the product was paraffinic and olefinic. Probably cyclic compounds were not present (see below).

The residue obtained from the liquid reaction product was hydrogenated (three times) at a maximal temperature of 225° C. with nickel as a catalyst. However, the hydrogenation was very difficult.

In Table II a survey of the results is given.

TABLE II.

Physical constants.	Raw material (fraction 2) before hydrogenation.	Distillate.			Residue	
		Distillate.	*n*-Pentane literature.	*n*-Hexane literature.	before hydrogenation.	after hydrogenation (3×).
Boiling point	—	35–62°	36°	69°	—	—
$n_D^{t°}$	1·4575	1·3740	1·3577	1·3751	1·4574	1·4503
$d_4^{t°}$	0·8170	0·641	0·6263	0·6595	0·8154	0·8169
$\frac{n^2-1}{n^2+2}\frac{1}{d}$	0·3337	0·356	0·3504	0·3472	0·3343	0·3292
Aniline point	80·7°	63°	about 60°	about 65°	42·4°	64·8°
Bromine value	13	—	0	0	—	—
Mean molecular weight (C_5H_8)	261	—	72	86	151	153
Chlorine percentage	0·05	—	—	—	—	—
Average number of rings per molecule	0·7	—	—	—	—	1

These data indicate an important destruction of fraction 2 under the conditions mentioned above. Roughly speaking, there was obtained:

Gases: 15% (by weight containing much methane and homologues).
Light distillate: (boiling point 35–62° C.) 40%.
Residue: (molecular weight 151) 45%.

The low-boiling fraction (distillate) cannot contain many cyclic products;

however, the residue is more cyclic than the raw material, but its mean molecular weight is lower.

However, the *total* amount of rings, as indicated by the specific refraction, has not changed much. Therefore the final result of the reaction is in accordance with a destruction, in which the paraffinic or olefinic chains break from the molecules, leaving behind the more cyclic part of the original molecules in the residue. From the paraffinic and olefinic chains are formed the gases and the greater part of the distillate.

(b) *Experiment with nitrogen (initial pressure about* 70 *kg./cm.*^{2}*), and* 10 *per cent. of a nickel catalyst, during* 1 *hour.* In this case also an important destruction was observed. It was indicated already by the increase (about 30 kg./cm.^{2}) of the pressure ($P_{0°\,C.}$) in the autoclave after the experiment.

In the same way as is described under (*a*) the quantity of A gas, B gas and liquid reaction product was determined.

Before the experiment.		After the experiment.	
Raw material (fraction 2),	28 g.	Liquid product + catalyst,	20·4 g.
Nickel catalyst	2·5 g.	A gas	13·9 g.
Nitrogen	8·0 g.	B gas	2·8 g.
Total	38·5 g.	Total	37·1 g.

The A gas contained practically no hydrogen, but consisted of nitrogen with a small amount of methane.

The B gas was not analysed. After filtration of the catalyst, 17 g. of liquid reaction product were obtained. The latter was analyzed without previous distillation and hydrogenated at a maximal temperature of 225° C. with nickel-on-kieselguhr as a catalyst. Complete hydrogenation was impossible, the quantity of material not being sufficient.

A summary of the results is given in Table III.

TABLE III.

Physical constants.	Raw material (fraction 2) before hydrogenation.	Liquid reaction product	
		before hydrogenation.	after hydrogenation.
$n_D^{t°}$	1·4575	1·5055	1·4726
$d^{t°}$	0·8170	0·8821	0·8575
$\frac{n^2-1}{n^2+2}\frac{1}{d}$	0·3337	0·3365	0·3269
Aniline point	80·7°	20°	56·6°
Bromine value	13	—	—
Mean molecular weight (C_6H_6)	261	180	178
Chlorine percentage	0·05	—	—
Average number of rings per molecule	0·7	about 1·3 (>1·3)	about 1·3 (>1·3)

Also in this experiment the destruction was important. At least 10 per cent. (by weight) of gases (with only a small amount of hydrogen)

had been produced. The mean molecular weight of the raw material was much higher than the molecular weight of the liquid reaction product.

It may be remarked that the liquid reaction product was strongly unsaturated and cyclic (see Table III). The number of rings in the liquid reaction product was about twice the number of rings of the raw material. In this case the total amount of rings had increased, as compared with the original product.

Delft, Laboratory of Chemical Engineering of the University.
May 1935.

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[1] J. C. Vlugter, H. I. Waterman and H. A. van Westen, "Improved Methods of Examining Mineral Oils, Especially the High-boiling Components of Non-Aromatic Character," *J.I.P.T.*, 1932, **18**, 735–750; J. C. Vlugter, Thesis, Delft, 1932; J. C. Vlugter, H. I. Waterman and H. A. van Westen, *J.I.P.T.*, 1935, **21**, 661–676.

[2] H. I. Waterman, J. J. Leendertse and W. M. Klazinga, *Rec. trav. chim.*, 1935, **54**, 79.

[3] H. I. Waterman, J. J. Leendertse and W. M. Klazinga, *loc. cit.*, Fig. 2.

THE PRODUCTION OF CYCLIC COMPOUNDS BY DESTRUCTION OF RANGOON PARAFFIN AT HIGH TEMPERATURE.*

By H. I. Waterman, J. J. Leendertse, L. Adam and C. van Vlodrop.

Previous investigations have shown that the heating of Rangoon paraffin wax at 450° C. for 90 minutes in an autoclave under the pressure of the gases produced during the reaction yields partly cyclic products.[1] The method of executing the experiments and also the method of analyzing the low-boiling fractions of the reaction product have been published.[1] Subsequently the portion of the reaction product boiling above 150° C. was fractionated into several fractions by distillation under vacuum and cathodic light vacuum.[2] The fractions were analysed,[3] using the specific refraction in connection with the mean molecular weight (after saturation of the olefinic and aromatic bonds by a careful hydrogenation) to indicate the cyclic character.[4]

The reaction products obtained in the experiments described below have also been investigated similarly.

In the case of the " cracking " experiment just mentioned, the cyclic character of the fractions is evident. To simplify the matter, the properties of the *hydrogenated* fractions are given in Fig. 1, in which points belonging to these experiments are indicated by the curve *C*.

A second series of experiments was performed under analogous conditions, but the paraffin wax was heated under high hydrogen pressure (initial pressure 100 kg./cm.^{2}). In consequence of the presence of the hydrogen, the production of rings in the reaction product was much smaller than in the case of the " cracking " experiment. The properties of the fractions after complete hydrogenation are given in Fig. 1, curve *B* being drawn through the corresponding points.

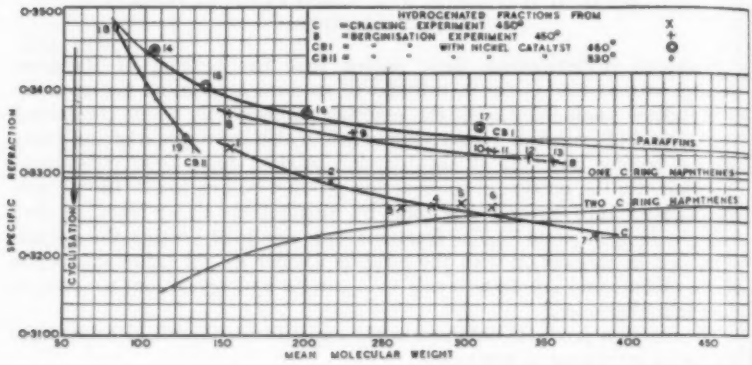
A third series of experiments was also performed under analogous conditions (460° C., for 1 hour). In this case nickel-on-kieselguhr was used as a catalyst.[5] The properties of the fractions obtained from the reaction product are also given in Fig. 1. (See curve *CBI*.)

At the time this investigation was not completely finished. From the results of these experiments it is clear that, under the conditions just mentioned, the hydrogenating effect of the combination high-pressure hydrogen and nickel catalyst prevents cyclization. The addition of high-pressure hydrogen without a catalyst already decreased considerably the production of rings (curve *B*). However, the simultaneous presence of a hydrogenation catalyst and high-pressure hydrogen caused a total absence of rings in the reaction product. The fractions obtained from the reaction product, indicated by the curve *CBI*, were practically completely saturated, and did not need an additional analytical hydrogenation.

By increasing the reaction temperature in the presence of nickel as a

* Paper received August 30th, 1935.

catalyst and (or) by reducing the quantity of hydrogen available in the reaction, the production of rings increased. This is proved by another experiment in which the reaction temperature amounted to 530° C. In this case the initial hydrogen pressure was also about 100 kg./cm.², but the partial pressure of the hydrogen after the reaction was low. The properties of the fractions obtained from the total reaction product after complete saturation with hydrogen are given in Fig. 1 (curve *CBII*).



No.	$n_D^{15°}$.	$d_4^{15°}$.	Aniline Point. ° C.	Bromine Value.	$\frac{n_\gamma' - n_c}{d} 10^4$.	No.	$n_D^{15°}$.	$d_4^{15°}$.	Aniline Point. ° C.	Bromine Value.	$\frac{n_\gamma' - n_c}{d} 10^4$.
1	1·4350	0·7840	70	—	—	11	1·4415, 40°	0·7943, 40°	108·7	0	—
2	1·4594	0·8324	76·4	0	—	12	1·4321, 70°	0·7789, 70°	111·7	0	151 to 152, 70°
3	1·4682	0·8536	87·2	0	155	13	1·4333, 70°	0·7819, 70°	115·8	0	153, 70°
4	1·4700	0·8567	90·8	0	159	14	1·3986	0·7011	72·2	0	—
5	1·4669, 40°	0·8491, 40°	94·5	0	158, 40°	15	1·4148	0·7356	81·8	0	about 156
6	1·4740, 40°	0·8611, 40°	97·2	0	166, 40°	16	1·4325	0·7699	90·4	0	159
7	PREDICTED:		100	0	—	17	1·4390, 40°	0·7824, 40°	106·8	—	—
8	1·4236	0·7565	73·0	10·3	—	18	1·3644	—	—	0	—
9	1·4416	0·7903	89·2	6·8	—	19	1·4249	0·7648	61·2	0	—
10	1·4402, 40°	0·7919, 40°	106·8	0	—						

TABLE I.

FIG. 1.

In this experiment the temperature was above 500° C. for only a short time (about 10 minutes), the total time of heating above 450° C. being about 25 minutes. The destruction to very low molecular components was considerable. About 44 per cent. (by weight) of the reaction product were gases, and about 20 per cent. was a gasoline with a boiling point below 65° C. The properties of the latter product indicated a practically completely saturated and paraffinic character. The portion of the reaction product with a boiling point above 65° C. was practically free from olefinic double bonds; however, it was partly cyclic, and contained some aromatic compounds. In the reaction 75 per cent. of the initial hydrogen was consumed. The gases produced in the reaction practically did not contain any olefines.

It should be noted that the specific refractions used in Fig. 1 do not correspond exactly with the figures given in the previous paper.[3] A tem-

TABLE I.

	Cracking fractions.						Berginization fractions.							
	C.C.V.D.I.C. I		C.C.V.D.I.C. II		C.C.V.D.I.C. III		B.C.V.D.I.C. I		B.C.V.D.I.C. II		B.C.V.D.I.C. III		B.C.V.D.I.C. IV	
	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.	Before Hydrogenation.	After Hydrogenation.
$\frac{n^2-1}{n^2+2}\frac{1}{d}$ at f° C.	0·3315 (20°)	0·3258 (20°)	0·3310 (20°)	0·3257 (20°)	0·3337 (40°)	0·3267 (40°)	0·3343 (40°)	0·3329 (40°)	0·3340 (40°)	0·3328 (40°)	0·3339 (70°)	0·3331 (70°)	0·3336 (70°)	0·3326 (70°)
$\frac{n^2-1}{n^2+2}\frac{1}{d}$ calculated for 20° C.	—	—	—	—	0·3332	0·3262	0·3338	0·3324	0·3335	0·3323	0·3327	0·3319	0·3324	0·3314
Aniline point (determined)	66·5°	87·2°	73·7°	90·8°	76·6°	94·5°	99·9°	106·8°	102·7°	108·7°	107·3°	111·7°	110·7°	115·8°
Aniline point read in revised graph	—	86°	—	90°	—	94½°	—	105½°	—	106°	—	109°	—	110½°
Bromine addition value	10·7	0	8·5	0	8·2	0	6·1	0	5·4	0	5·1	0	4·7	0
Molecular weight [1]	259 (*b*)	259 (*b*)	278 (*b*)	278 (*b*)	301 (*b*)	298 (*b*)	312 (*b*)	311 (*b*)	319 (*b*) 314 (*n*)	315 (*b*)	334 (*n*)	338 (*b*)	351 (*n*)	351 (*b*)
Average number of rings per molecule	1·7		1·65		1·65		0·4		0·4		0·45		0·55	
Aniline point of the completely hydrogenated product predicted from molecular weight, aniline point and specific refraction of the product before hydrogenation	—	89	—	93	—	99	—	106	—	107	—	109	—	112
Percentage by weight of aromatic rings calculated from observed increase of aniline point	18	—	15	—	15	—	6	—	5	—	4	—	4	—
Percentage by weight of polycyclic six-ring naphthenes [2] in the completely hydrogenated fraction	—	38	—	36	—	33	—	8	—	8	—	8	—	10
Percentage by weight of polycyclic six-ring naphthenes [2] in the fractions [3]	20	—	21	—	18	—	2	—	3	—	4	—	6	—

[1] (*b*) = determined by the lowering of the freezing point of benzene, (*n*) = determined by the lowering of the freezing point of naphthalene.

[2] , etc.

[3] Not considered the hydrogen which was consumed in the hydrogenation of the aromatics.

perature correction for the specific refraction has been applied, as described later. Further details on the hydrogenated fractions Nos. 1 to 19 are given in the table in Fig. 1.

In the previous paper[3] the majority of the specific refraction determinations was done at 40° C. and 70° C., whereas the number of rings was read on a graph which was based on the specific refractions at room temperature. The relation between the temperature and the specific refraction is roughly known for hydrocarbon mixtures between 20° C. and 70° C. The specific refraction increases at higher temperature by about 0·000025 per ° C. Therefore, the specific refraction values could be calculated for 20° C.

Thus it is found that the number of rings in the berginization fractions becomes 0·4–0·5, while this number becomes 1·6–1·7 in the cracking fractions. The essential difference between the cracking and the berginization fractions therefore remains unaltered. The results of the revised calculations are found in Table I.

Use was also made of a revised aniline point–molecular weight–specific refraction diagram.[4] The percentage of aromatic rings could be calculated from the aniline point increase observed by the analytical hydrogenation of the fractions investigated.* With 0·85 per cent. by weight of aromatic rings the aniline point is decreased by about 1° C.

By supposing the presence of a special ring system, *e.g.* polycyclic six-ring naphthenes, the percentage by weight of these rings could be calculated in the wholly hydrogenated product. By subtracting from this percentage the percentage of aromatic rings of the fraction before hydrogenation, the percentage of polycyclic six-ring naphthenes was found.

From Table I it is seen that the cyclic character is caused by naphthenes as well as by aromatics. The exact proportion of these two groups cannot be calculated, because this depends on the type of naphthenic rings which are present.

Conclusions.

From the experiments mentioned above it can be concluded that, in the pyrolysis of Rangoon paraffin wax, it is possible to control the cyclic character of the reaction products. It is even possible completely to prevent ring formation.

Experiments with non-paraffinic raw materials will be executed in due course.

Delft, Laboratory of Chemical Engineering,
June 1935.

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[3] H. I. Waterman, A. J. Tulleners and J. Dooren, *Proc. Kon. Akademie van Wetenschappen, Amsterdam*, 1932, **35**, 1063.
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[5] H. I. Waterman, A. J. Tulleners, W. J. Hessels and G. M. D. Vogelsang, *Comptes rendus du 10me congrès de chimie industrielle*, 1930, **25**, 390–395.

* The influence of the unsaturation of olefinic character as is shown by the bromine addition value is small, and practically can be neglected.

ON THE VISCOSITY CHARACTERISTICS OF CHEMICALLY DOCTORED DRILLING FLUID.

By C. A. ANDREWS, Ph.D., A.M.I.Min.E., A.M.Inst.Struct.E.

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SYNOPSIS.

The paper opens with a discussion of the structure conditions and flow characteristics of thixotropic liquid–solid suspensions and mixtures containing particles of colloidal and/or macroscopic magnitude. Problems in viscometry introduced by thixotropy, in particular reversible hydrosols, are considered with reference to rotary mud.

By means of concentration–viscosity curves, points of minimum viscosity are given for kaolin–water mixtures which have been "doctored" with electrolytes such as might find use on an oilfield where the viscosity of drilling fluid has to be controlled.

Symbols Used.

G = Velocity drop.
η = Viscosity coefficient.
τ = Tangential force occasioned by fluid flow.
θ = Yield value.
Q = Quantity of flow.
t = Time.
R = Radius of capillary tube.
L = Length of capillary tube.
p = Pressure.
μ_0 = Minimum Mobility.
μ_∞ = Maximum Mobility.
Ω = Angular velocity.
R_e = Outer radius, rotary type viscometer.
R_i = Inner radius, rotary type viscometer.
D = Torsional resistance.
l = Length of submerged section, rotor of rotary type viscometer.
ϕ = Angular displacement of wire supporting internal cylinder, rotary type viscometer.
M = Turning Moment.
a = Numerical factor.
η' = Viscosity of liquid phase.
F = Ratio of volume of solid phase to total volume of suspension.
η_∞ = Viscosity when velocity drop across section is very large.
η_0 = Viscosity when velocity drop across section is very small.
σ = Shear stress.
α = Angle of inclination.
γ = Specific gravity.
$x' = \frac{\pi R^2}{2L}$.
$x'' = \frac{D}{4\pi l}$.
C = Rate of change from μ_0 to μ_∞.

WHEN drilling by means of the rotary system, the detritus or stone splinters are removed from the well by means of a mixture consisting essentially of clay and water, which is kept in circulation during the drilling process. This mixture is called "mud" on the field, but, due to the growth

of the practice of "doctoring," the expression "drilling fluid" is a better and more inclusive designation.

With the increasing depths to which wells are being drilled, the characteristics of this fluid are important factors contributing to the successful termination of the drilling programme. This is evident when the functions of the fluid are considered. Such are well known, and need no recapitulation here. It is sufficient to state that those touched by the considerations in this paper are :—

(*a*) The removal of the detritus or "cuttings" incidental to the penetration of the strata through which the bit passes. Velocity conditions being equal, this depends to a large extent on the viscosity of the fluid.

(*b*) The holding of solid particles in suspension should circulation be interrupted.

(*c*) The maintaining of a hydrostatic head in order to control either, (*a*) movement or caving in of strata being penetrated or already passed or, (*b*) the flow of high-pressure gas, oil or water into the well.

When the functions above detailed are considered, it would appear that a viscous fluid of high specific gravity would meet the requirements. This is not so, because in the case of wells of no more than moderate depth the circulation of a highly viscous fluid could be effected only with the aid of pumping units of great power. Further, the detritus brought to the surface could not be removed from the circulating troughs with the necessary rapidity even with the aid of sieves.

The fluid therefore has to be such that it possesses a relatively high specific gravity and a low viscosity. The latter characteristic will permit the solid particles to settle rapidly when circulation is stopped, and as this must be avoided, the fluid should have the capacity of increasing its viscosity within a few minutes after being brought to rest. This combination of a low viscosity when in motion and a high viscosity when at rest can be attained where a thixotropic substance is used. When in motion, the substance behaves as a liquid, and is a sol; when at rest, it is more or less a rigid mass or gel. As motion and rest alternate during the drilling process, the fluid must be alternately a sol and a gel. Hence a solution is found in the production of a drilling fluid which is a thixotrope or a reversible hydrosol.

Inasmuch as a viscosity control of the fluid is essential, the attaining of the desired conditions in the production of a reversible hydrosol has introduced a difficulty. Viscosity determinations now have to be made upon a substance which is a fluid only when in a turbulent state of motion.

Viscosity of Colloidal Suspensions.

The word "viscosity" cannot, in the manner in which it is usually defined, be used in connection with the flow characteristic of a drilling fluid. Viscosity may be defined as the resistance exerted against intermolecular lineal flowing motion in the interior of a homogeneous substance; in other words, the force which is overcome when the molecules are in steady flowing motion relative to each other. This force is a constant for the same sub-

stance under the same conditions of pressure and temperature and velocity gradient. In the case where viscosity determinations of liquids are being made, the motion of the molecules must be a sliding or gliding one, and flow conditions are so controlled that turbulent motion is avoided. Such determinations are made without undue difficulty, but when it is necessary to ascertain the viscosity of a fluid such as a colloidal suspension, many difficulties are encountered.

The internal conditions of the fluid are quite different, and one no longer has merely the friction of molecule on like molecule to consider. The substance now consists of a dispersion phase and a disperse phase. The so-called viscosity is a combination of three friction factors :—

(*a*) That of the molecules of the liquid phase in contact with similar molecules.
(*b*) That of the molecules of the liquid phase in contact with the particles of the disperse phase.
(*c*) That of the particles of the disperse phase in contact with each other.

It follows as a consequence of the new factors (*b*) and (*c*) that the magnitude of the total interior frictional resistance to flow depends to a great extent on the concentration of the disperse phase, and the dimensions of the individual particles of which that phase consists.

The dependence of the viscosity on the concentration of the solid phase can be regulated within certain limits. On the other hand, the viscosity complications induced by the dimensions of the particles of the solid phase are of importance, and difficult to control. The particles have not only various dimensions, but are also different in their form, so that with a changing of concentration and particle size the number of contacts with the neighbouring particles will vary.[1] Other reactions may be affected or influenced. In many cases a chemical reaction takes place. This has very often a considerable, sometimes even a controlling, influence on the viscosity of the fluid. From the chemical standpoint an equilibrium involving, for instance, dissociation, polymerization, etc., may be established between the liquid and solid phases of a suspension.[2]

Another factor, the physicochemical one of adsorption, must appear in all cases. The influence of adsorption on the viscosity of a suspension can be extraordinarily great and far-reaching.[3] It can influence the particles of the solid phase in many ways. Apart from the alteration in the internal and external structure of the particles by such phenomena as penetration of the liquid into the interior, swelling, etc., adsorption gives rise to the formation of a surface film.[4] Such a film not only increases the effective volume of the particle, it also qualifies the friction conditions. So far as the internal friction is concerned, the presence of an adsorbed film changes viscosity conditions by reason of its thickness, its elasticity, its coefficient of friction, its resistance to destruction by shear stresses, etc. It is obvious that each or all of these properties can and do affect the internal friction between the phases of a colloidal suspension.

All of the above factors which may vary the viscosity of a colloidal suspension can be further complicated by the presence of an electrolyte.[5] Should this be the case, the relative attraction or repulsion called into being by changes in the electric potential of the charge on the individual particles

can materially affect the viscosity.[6] Here also the concentration and the size of the particles play a part, for the magnitude of the forces interacting between them depends to a certain extent on their distance apart.[7]

When the concentration of a suspension is relatively high—that is to say, when it is such that the fluid may be termed a mixture as distinct from a suspension—either or all of the above-mentioned factors can influence the shear stress of the mass. In other words, the force which must be exerted to separate the particles one from another when the mixture is under shear stress is changed in magnitude. The yield point of the mass has altered. Consequently the so-called viscosity is a resultant of the real viscosity and the shear force. This characteristic cannot, therefore, be designated as viscosity in the strict sense of the word. It might better be called the "flow characteristic" of the mass, which now has a style of flow similar to, but not the same as, that called "solifluxion."

Carrying the consideration further to include the case of a clay–water suspension or mixture, it becomes obvious that from both physical and chemical standpoints a drilling fluid is even more complicated than the usual colloidal suspensions. By far the greater weight percentage of the particles of the solid phase are larger than colloidal in size. With particles of such dimensions differences in shape can adopt a greater number of variations. Different clays, shales, etc., have different chemical compositions, from which it follows that not only the particles themselves, but also the adsorbed film and the reactions in the presence of an electrolyte, will be susceptible to an almost infinite number of variations.

Altogether, it may be said that the conditions are to the highest degree involved so far as the internal friction and, in the case of a highly concentrated mixture, the shear force, are concerned. This to such an extent that every clay–water suspension possesses characteristics which render it different from any other.

Turbulent Viscometry.

As previously stated, a drilling fluid may be so constituted that when the circulation is stopped a gelling action will occur, with the result that the sand-pumpings as well as the particles of the disperse phase will be held in suspension until circulation can again begin.

Most mixtures used as drilling fluids contain a relatively high percentage of extremely small particles. Except for a very small percentage, these particles are far larger than colloidal in dimension. The fact that the particles are small, also that in the solid material used there are particles of such substances as hydrated aluminium oxide, hydrated ferric oxide, etc., which assist the action, enables the mixture to possess to a small extent the capacity to gel. The gelling action, however, is as a general rule quite weak, and, moreover, such a period is needed before the gel stage is reached, that there is ample time for settling of the larger particles to take place. In order to accelerate and accentuate the gelling action, various substances can be added to the fluid. The effect of these in some cases is so rapid that almost immediately after the stopping of circulation the sol becomes a gel, a complication which introduces the greatest difficulties when it is required to make a viscosity determination with the fluid. The method usually

adopted—that in which the viscosity is determined after observations made respecting the time taken for a given quantity of the fluid to flow through a capillary or an orifice—is quite unsuitable. Where the gelling action is very rapid the mass cannot flow through a reasonably sized orifice or capillary, although where the action is slower, the fluid will flow should the orifice be sufficiently large. Inasmuch as the gelling action is proceeding during the time of the test, there is no doubt that the change of viscosity during this period is such as to cause time readings to be made which will lead to unreliable results being obtained.

The ability of the fluid to gel at normal temperatures and pressures depends on the relative motion of the particles of which the mixture is composed. A thixotrope will be converted into a sol when the mixture is forced through a capillary at a velocity such that turbulent instead of stream-line motion is imparted to the particles. Conversely, at a rate of progression below this critical velocity, the sol, either in part or in its

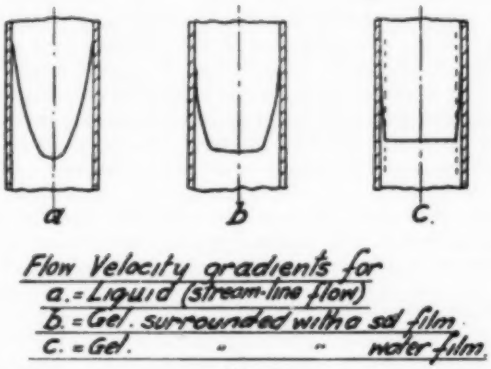


FIG. 1.

FLOW VELOCITY GRADIENT CURVES IN A CAPILLARY TUBE.

entirety, will become a gel. Within certain velocity limits, and at pressures under a certain magnitude, that part of the mass in direct contact with the walls of the capillary will be a sol, whilst the centre moves forward as a gel. In this centre core there is no relative motion between the particles of which the mixture is composed. Such motion is restricted to the sol film. Where the gel action is rapid and, in addition, synaeresis occurs, the film actually in contact with the walls is composed almost entirely of liquid. A comparison of flow velocity gradient curves is given in Fig. 1. For the flow through a capillary of (*a*) a liquid, (*b*) an ordinary gel surrounded with a sol film and (*c*) a gel surrounded with a film of water. In the latter two cases it is obvious that the rate of progress depends to a certain extent on the weight of the core of the moving mass. The proportion of the tube diameter over which relative sliding motion of the particles takes place will, of course, vary with the type of gel and the velocity with which it is flowing, but in most cases it is improbable that this motion will take place over the whole cross-section, as is the case when a liquid flows along a capillary of chosen diameter at a suitable speed.

Rideal [8] states, as a result of experiments with a silica gel, that the viscosity values obtained during the course of experiments with a flow type of viscometer did not agree with those given by a viscometer of the shear type. He deduced that the difference was due to the fact that whilst flowing through a tube the gel fibrils, or colloidal aggregates such as micellæ, oriented themselves in the direction of flow, whereas with the other type of instrument a certain amount of force was required to separate or fracture these structures. Such an orientation conformation was actually observed by Freundlich [9] and Kruyt.[10] When a vanadium pentoxide sol was allowed to flow through a tube, fibrils up to 1 cm. long oriented their major axis in the direction of flow. Finally they proceeded as one mass, no fibril moving relative to its neighbour.

On these and similar grounds Wo. Ostwald states, " . . . that the viscometry of colloidal systems cannot be considered only from the point of view of laminary flow, but more probably with more correctness from that of turbulent flow." [11]

Duckham [12] expresses the opinion that the existing types of viscometers are unsuitable for the determination of the viscosity of a drilling fluid. Meyer,[13] Herrick,[14] Wayne,[15] Ambrose and Loomis,[16] Kerr,[17] Parsons,[18] Zimmer,[19] etc., all direct attention to the difficulties attendant on viscosity determinations when gels, colloidal or similar systems are investigated.

The Stormer, Couette or other viscometers operating on like principle can, at certain speeds, induce a turbulence in the fluid under test. Nevertheless, in the event of rapid gel-building or synaeresis, unreliable results are obtained. The connection between viscosity and time in the case of thixotropic substances leads McMillen [20] to reach the conclusion that with a Stormer viscometer trustworthy results could not be obtained. Reiner [21] observes that for colloidal suspensions the Couette type of viscometer was unsuitable. Merkel [22] attributes the uncertainty of viscosity measurements made by means of viscometers operating on the rotating principle to phase separation during the gelling process (" weeping " or " seeping "), giving rise to the formation of a film in direct contact with the moving surfaces. The water content of this film is higher than that of the suspension as a whole, a fact which facilitates sliding or slipping on the part of the rotating element.

From the foregoing it is obvious that the apparent viscosity of a thixotropic drilling fluid is, amongst other factors, a function of (*a*) the internal friction, (*b*) the magnitude of the internal shear forces which are required to overcome the tendency of the particles to stabilize either as gel fibrils or micellæ and (*c*) time.

The viscosity of colloid suspensions have been investigated by Wo. Ostwald [23] over a wide range of velocities of flow, and he expresses the results in a pressure–velocity of flow curve such as is given in Fig. 2. Here the internal flow conditions are divided into three continuous parts: (*a*) that where the structure of the fluid is being overcome, (*b*) the Hagen–Poiseuille section, where flow continues as a stream-line motion of the particles and (*c*) that where the velocity has increased to such an extent that turbulent flow has commenced. It is within this latter sphere that the flow conditions of a gelling drilling fluid must be included.

Reiner [24] considers the case of the measurement of apparent viscosity by

means of a capillary and a viscometer of the rotation type. The latter consists of two co-axial cylinders, the outer, holding the fluid under test, being rotated with a given angular velocity, whilst the inner, which is suspended in the fluid by means of a wire with known resistance to torsional stress, serves to transmit to the wire the turning moment created by the friction effect of the moving fluid.

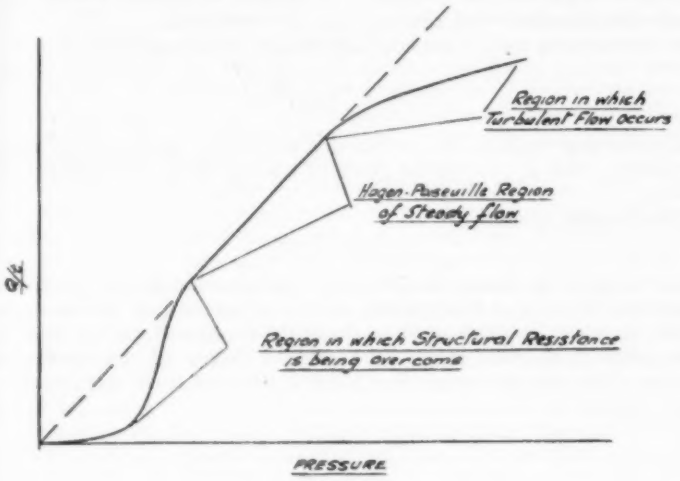


FIG. 2.

TYPICAL PRESSURE–VELOCITY OF FLOW CURVES FOR NON-NEWTONIAN FLUIDS (AFTER WO. OSTWALD).

From the initial equations :

$$G = \frac{1}{\eta_i}(\tau - 0) \quad \text{or} \quad \tau = \eta_i G + 0$$

and

$$G = -\frac{\tau p}{2l\eta_i} \quad : \quad G = \frac{M}{2r^2\pi l\eta}$$

where the two latter apply to the velocity drop for the cases of the capillary and the rotation types, respectively, he derives a general equation

$$G = \mu_0(\tau - 0) + \frac{\Sigma}{2}\frac{f^{(n)}(0)}{n\,!}(\tau - 0)^n$$

Integrating this formula for the capillary and rotary cases he derives :

$$\frac{Q}{t} = \frac{R^3\pi p}{2l\eta} + \mu_0\frac{pR^4\pi}{8l} + \frac{\Sigma}{2}\frac{f^{(n)}(0)}{n\,!}\left(\frac{p}{2l}\right)^n\frac{R^{n+3}\pi}{n+3}$$

$$\Omega = \frac{D\phi}{2\pi l\eta}\frac{R_e^2 + R_i^2}{R_e^2R_i^2} + \mu_0\frac{D\phi}{4\pi l}\frac{R_e^2 - R_i^2}{R_e^2R_i^2} + \frac{\Sigma}{2}\frac{f^{(n)}(0)}{n\,!}\left(\frac{D\phi}{2\pi l}\right)^n\frac{1}{2n}\frac{R_e^{2n} - R_i^{2n}}{R_e^{2n}R_i^{2n}}$$

The first element of the equations is the external friction, the second is the internal friction of a Newtonian fluid, whilst the third and following are those expressing the resistance to deformation caused by the structure peculiarity of non-Newtonian fluids. The number of these elements is infinitely great, but this does not mean that for the mathematical description of the hydro-dynamical conditions of the respective fluid an infinite number of constants are necessary. According to Reiner, the results of observations indicate that five only may be considered.

A treatment of these constants leads finally to the equation

$$f^{(n)}(0) = \frac{\mu_\infty - \mu_0}{C^n - 1} n\,!$$

where the new constant C is a function depending on the rate of change between μ_0 and μ_∞, *i.e.* of the grade of lability of the structural characteristic.

The Einstein formula :[35]

$$\eta = \eta'(1 + \alpha F)$$

is now utilized to deduce the following equations for the two types of viscometer. The use of this formula must be accepted with certain reservations, because the value of F is obviously dependent on the effects of absorption on the solid phase. For instance, the particle may swell or subdivide, whilst the absorption film which is attached to the particle surface may vary in thickness from case to case.

$$\frac{Q}{t} = \frac{x'p}{\eta_0}\left[1 + \frac{16}{5R^3\pi} C \frac{\eta_0 - \eta_\infty}{\eta_0} \frac{x'p}{\eta_0} + \ldots\right]$$

$$\Omega = \frac{x''\phi}{\eta_0}\left[1 + \frac{R_e^2 + R_i^2}{R_e^2 - R_i^2} C \frac{\eta_0 - \eta_\infty}{\eta_0} \frac{x''\phi}{\eta_0} + \ldots\right]$$

Plotting the above equations with $\frac{Q}{t}$ and Ω as co-ordinates, and p and ϕ as abscissæ, respectively, we have a theoretically derived curve which has the same general characteristics as the curve of Fig. 2.

It is of importance to note that during the course of the mathematical deduction Reiner replaces the physical characteristic " viscosity " with that of " fluidity." As this is defined as the measure of the velocity with which a fluid is deformed by the action of a tangential stress, the time element is included.

A result of the above consideration leads to the conclusion that in order to obtain viscosity measurements which can be reproduced, and which are of value for fields use, such measurements should be made by means of an instrument which agitates the entire mass of the sample under test whilst the necessary readings are being made. A structure turbulence must be maintained which is sufficient to keep the sample in a labile state—that is to say, the state in which it is used when in circulation during the drilling process.

Viscometry of Drilling Fluid.

A series of experiments conducted with various types of apparatus led to the conclusion that the best results could be obtained with a Dallwitz-

Wegener viscometer.[26] Nevertheless, with samples in which the concentration of the solid phase was high, or which had been chemically treated in order to induce a strong gelling action, the driving mechanism was not strong enough to rotate the shaft carrying the spiral. This difficulty was overcome when a viscometer on a similar principle was constructed. Instead of a shaft on which a spiral was mounted, the moving parts were spur wheels. Ignoring peculiarities in design found to be necessary during the course of the design of the instrument, it was essentially a spur wheel pump provided with inlet and outlet tubes. In the outlet tube a pressure-measuring apparatus was inserted, this being either a water or mercury manometer or a pressure gauge. Under chosen running conditions the pump delivered constantly the same volume of fluid. When the outlet line was throttled, then in the same moment the delivered volume became less, whilst the recorded pressure increased; if the throttling was carried on until no flow took place, the pressure rose, but only to a certain point, at which it remained constant. This indicated that an equilibrium had been established between the fluid delivered and that which flowed backwards through the pump interstices. The greater the viscosity of the mixture, the greater was the pressure which must be produced to enable the same quantity to flow backwards in the same time. The pressure attained when equilibrium conditions exist can be used as a measure for the viscosity of the fluid under test, provided that the instrument has been calibrated with fluids of known viscosity.

Spur wheels of a steel of special hardness were used, this material being chosen on account of the abrasive action of the harder particles in the clay–water mixtures used. The instrument was so made that play in the wheels was reduced to a minimum.

By means of a funnel the clay–water mixture was fed into the suction side whilst the wheels were in motion. It was promptly conveyed to the delivery side, the connections here being so arranged that the fluid was returned to the funnel. The method of obtaining a reading necessitated that the fluid was two or three minutes in circulation. The delivery side was then closed by means of a valve and the pressure recorded on the manometer.

The instrument was driven by a slow-running continuous-current motor, a special gearing being interposed between this and the pump in order that the wheel speed of the latter could be varied at will to 1, 2, 5, 10, 20, 50, or 100 r.p.m.

Temperature Control.

Inasmuch as it was proposed to ascertain data relating to the flow characteristic of a clay–water mixture by means of the above described system with either an open or a closed circuit, it was considered possible that there would be a distinct temperature rise during the period of the test. This might be appreciable when the revolutions were high owing to the conversion of mechanical energy into heat. Should the temperature rise be considerable, a corresponding viscosity change would take place during the test period. This would necessitate the continual use of a method of temperature control such as a cooling coil in the flow-circulating system.

Accordingly, circulating runs of long duration were made, during the course of which the fluid temperature was recorded by means of a calibrated

sensitive thermometer. The results of two typical tests in which spindle oil and a kaolin–water mixture were used are given in the curves shown in Fig. 3. It will be seen that there was a small temperature increase, after which no further rise was observed, apparently because a heat equilibrium was established between the system and the surrounding air. The oil showed the greater temperature rise, this being attained after circulating for 2 hours. The increase in temperature for the mixture—*i.e.* 0·8° C.—is so small that one may assume that for practical purposes it is negligible, especially as, under normal conditions, the duration of a test would not exceed 5 minutes.

Various factors may conduce to error in the viscosity determinations, the chief of which is that originated by lack of symmetry in the pump due to inexact workmanship or wear due to abrasion. The most sensitive parts of the instrument in this respect are the spur wheels, the clearance between

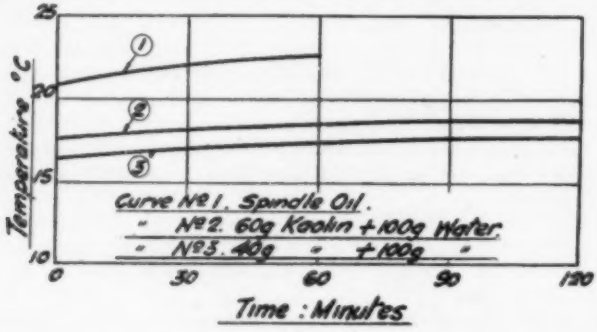


FIG. 3.

TEMPERATURE INCREASE OF FLUIDS UNDER TEST CAUSED BY MECHANICAL HANDLING.

these wheels and the pump housing, and bearings carrying the wheels. An alteration in any of these clearances gives rise to variations in the recorded pressures. Such changes in pressure were particularly to be remarked when the rate of working was 1–5 r.p.m. At the commencement of the tests a pressure pulsation was registered with maximum and minimum points always occurring within certain limits. This periodic pressure swing was found to synchronize with the speed of revolution of the pump. At higher speeds these oscillations were negligible, either on account of damping or the inertia of the fluid system, for at these speeds the recorded pressures remained constant.

Quartz grains and other particles composed of hard minerals, such as are often found in clays and shales, entering between the wheel teeth would cause a momentary displacement of the wheels, which would result in a pressure variation. This also was most noticeable at lower speeds, but scarcely perceptible when higher speeds were used. Particles of this description gave rise also to wear through abrasion. Hence the mixtures were always sieved through a 200 mesh before being tested. Apparent viscosity results are likely to be little affected by the removal of these

particles, as their influence either on the specific gravity or the viscosity is very minute.

In consequence, pressure reading in tests with clay–water mixtures commenced at 10 r.p.m., but where kaolin was used readings could be taken at lower speeds, owing to the uniformity of this material as regards particle size and chemical constituents.

Another possible source of inaccuracy is to be found in the length of the tube between the pump outlet and the manometer. This must be as short as possible, in order that the possibility of irrelevant pressure losses may be eliminated.

When used with clay–water mixtures the instrument is readily cleaned by running a " slug " of water through the pump and circulating system. Where readings at high temperatures are required, the material can flow through a coil in a thermostat placed at the inlet side.

The system and type of instrument have one definite advantage: continuous readings can be taken. Should a mixture of different apparent viscosity be poured into the inlet funnel, it is found that within a very short time, depending on the speed at which the spur wheels are revolving, a " slug " of the freshly added mixture will have reached the manometer, and a change in pressure is recorded which is due to the variation in the flow characteristic of the fluid being circulated. This latter factor can be utilized to obtain permanent viscosity charts where a recording pressure gauge is used.

Precise scientific accuracy will not be given with the instrument as used, but reliable and reproducible comparative results may be quickly obtained.

Gel Resistance to Shear.

The fact that a thixotropic drilling fluid when at rest possesses a definite resistance to flow due to its structure as a gel, necessitates an investigation as to the magnitude of the force required to break this structure. Should it be considerable, then the shear stress would be so great that it would not be possible to consider the fluid as a Newtonian liquid. A non-Newtonian fluid of this gel type would have an influence on the accuracy of the pressure gauge reading because the transfer of pressure from the spur wheels to the gauge can take place only with the fluid itself as the conducting medium. In the event of the mixture possessing a relatively high resistance to shear—that is to say, a high yield value—it would transmit the pressure incompletely, because a part of the pressure would be lost through being absorbed in overcoming shear force. In this case the pressure recorded on the gauge would be too low.

For experimental purposes it was necessary to use a clay–water mixture of reasonably uniform qualities; hence kaolin was chosen, on account of the fact that the particle size gradient is fairly regular, as is also the chemical constitution of the material compared with that of the usual clay. Accordingly, experiments were conducted with kaolin–water mixtures of 40 g. kaolin with 100 g. water to which various chemicals in various concentrations were added, the quantity of chemical being a weight percentage as compared with the distilled water. These mixture proportions were chosen because they gave a mixture with a specific gravity of 1·151.

Although this is somewhat on the low side, a kaolin–water mixture of such proportions has a higher apparent viscosity than that of a mixture of the same proportions composed of clay as used in practice. This is due to the larger percentage of smaller particles in the kaolin.

The kaolin was dried at 105° C., cooled to 18° C., then added to the liquid, the resultant mixture being then gently agitated on a shaking machine for 15 minutes. It was allowed to stand for 3 to 4 hours, this time not being exceeded, in order that the complications due to ageing effects might be avoided. These would have an influence on the viscosity of the fluid, and on this account freshly prepared mixtures were always used.

Glass tubes of 3·0, 3·5, 4·5, 5·0, 6·0, 7·0 and 8·0 mm. diameter were fastened to a specially prepared plate which could be rotated in a manner such that from the horizontal the tubes could slowly be brought to the vertical. Columns 20 cm. long of the mixtures were then filled into the tubes. After a period of rest, the plate was slowly rotated towards the vertical at the rate of about 2° per minute. Typical results are those given in Fig. 4. They are for the cases where distilled water, potassium aluminium sulphate solution and a solution containing equal weight proportions of sodium silicate and aluminium sulphate were used. This latter solution was made on account of the fact that these chemicals have found considerable use in the doctoring of rotary mud.

At that point at which the mixture began to flow the angle of inclination was noted and the shear stress calculated by means of the formula :

$$\sigma = \frac{R\gamma}{2} \sin a.$$

The results show that the yield value of the kaolin–water mixture is low, and that the addition of these particular chemicals increases that value. The ascertained shear stresses vary to such an extent about a mean that a precise figure was difficult to determine. However, one can say that the value lies between 0·2 and 0·6 g./sq. cm., the mean being about 0·4 g./sq. cm. As the diameters of the tubes increase the shear stress appears to be greater. The explanation of this is perhaps to be found in the possibility that in a tube of the larger size, micellæ or fibrils can attain greater dimensions and have a better opportunity for the forming of a complicated structure through better interlocking. In any case, the actual ascertainable increase was naturally very small, and, irrespective of the size of the tube, once flow had commenced it would continue, even if the plate were rotated in the reverse direction, *i.e.* when the angle of inclination was decreased.

It appears from these results that one is safe in assuming that the mixtures have to all intents and purposes the properties of a Newtonian fluid when in motion, although as soon as they reach a state of rest they become a gel. Hence when the pressure differential generated by a viscometer is small, then the yield value exercises a considerable influence on the obtained reading. With higher pressure differentials such as are used in drilling practice the resistance to flow occasioned by gelling will be smaller, because by such pressures more rapid flow is assured. When the flow is turbulent any inaccuracy of the apparent viscosity reading due to the capacity to gel may be for practical purposes ignored, although it must be borne in

mind that the tendency to attain a structural equilibrium remains inherent in the mixture and, consequently, must be overcome in order that flowing motion may continue.

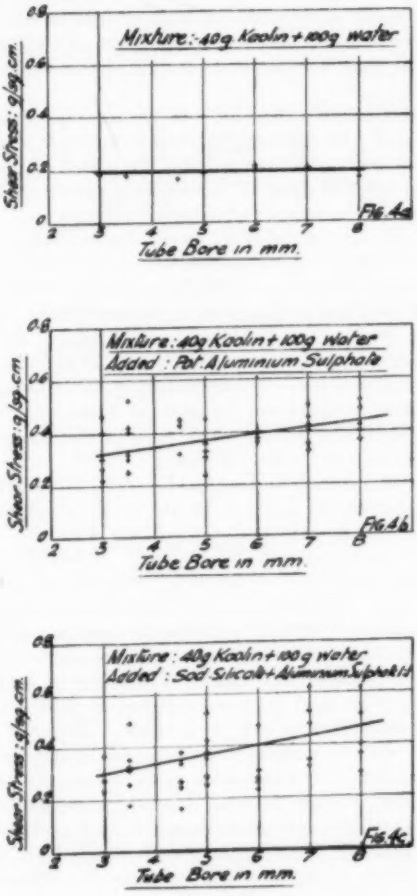


FIG. 4.

CHANGE IN SHEAR STRESS OF A KAOLIN–WATER MIXTURE INDUCED BY CHEMICAL DOCTORING.

EFFECTS OF "DOCTORING" UPON THE APPARENT VISCOSITY OF DRILLING FLUID.

The condition of a clay–water mixture can be greatly changed by the addition of certain substances. These affect flocculation, gel building, etc., and, of course, the reverse actions such as precipitation and peptization.

Another substance, or a greater quantity of the same substance, can in some cases prevent or even reverse the action. In general, such a substance is added to a drilling fluid, in order to alter its apparent viscosity to suit requirements or to influence the gel action. The actual rate of change of the latter action naturally depends on various factors which lie outside the scope of this paper, *e.g.* the chemical composition of the clay, the *p*H value, the concentration, the magnitude and sign of the electric charge of the particles,[27] etc.

In practice the object attained by " doctoring " is a drilling fluid of high specific gravity and low viscosity, although the converse condition may sometimes be required. The normal specific gravity of a rotary mud lies between 1·15 and 1·3, although by the addition of materials of high specific gravity this figure can be raised to 2·0 or even higher.

Mixtures of high specific gravity, with the attendant relatively high viscosity, give rise to pumping difficulties as well as inefficient detritus separation. The addition of a suitable substance can lower the viscosity.

The control of viscosity by this means is attended with many difficulties, which up to the present are far from being solved. The disperse phase varies in concentration and, in any case, varies in such matters as crystalloid and colloid content, etc. Further, during the drilling process various salts in crystal form, or which are dissolved in water, are combined with the mixture. There is another factor which must be considered: the temperature increase to which the fluid is subjected.

The chemicals which have been used for viscosity control are, amongst others, calcium hydroxide, sodium silicate, sodium sulphate, sodium tannate, caustic soda, soda ash, and very dilute solutions of acids such as sulphuric and hydrochloric. H. M. Marsh [28] states that sodium silicate, as well as sodium hydroxide or sodium carbonate, in general, lower the viscosity of a mud. Fisher [23] ascertained that a mixture of sodium aluminate and sodium hydroxide considerably increased the viscosity of a swelling clay, but had practically no influence on a non-swelling clay. M. Trouillard [29] reports on the effects of the use of sodium silicate and aluminium sulphate as used on the Pechelbronn field. Duckham [12] discusses the use of soda ash and sodium chloride. Meyer [13] refers to the use of " sodium salts such as silicate, phosphate, carbonate and hydroxide."

The addition of these substances for viscosity control is almost solely a matter of experience, because their use depends entirely on the chemical and physical properties of the mud under consideration on that particular well. Accordingly, in practice the chemical control is left in the hands of an engineer, who follows methods which by force of circumstances must be largely empirical.

In view of the effects induced by " doctoring " drilling fluids by means of various chemicals, investigations were conducted using substances such as are known to give rise to changes in the flow characteristic of the fluid. The chemicals and substances actually used included sodium sulphate, sodium carbonate, sodium silicate, potassium nitrate, calcium fluoride, sodium potassium tartrate, caustic soda, sodium chloride, thorium nitrate, potassium, aluminium, aluminium sulphate.

Kaolin–water mixtures were prepared in a manner similar to that previously described, the proportions 40 g. kaolin to 100 g. water being used

throughout, the chemical being added to the distilled water in definite quantities by weight.

The results obtained in the cases quoted above cannot be given in full

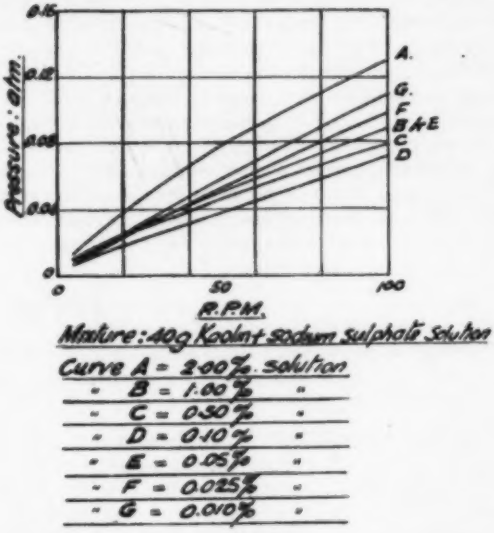


FIG. 5.

R.P.M.–PRESSURE CURVES OF KAOLIN MIXED WITH SODIUM SULPHATE SOLUTIONS OF DIFFERENT CONCENTRATIONS.

here. Those for aluminium sulphate, caustic soda, calcium sulphate, sodium sulphate, sodium carbonate, sodium silicate, and a mixture of aluminium sulphate and sodium silicate are produced, as these may be expected to be of more general interest.

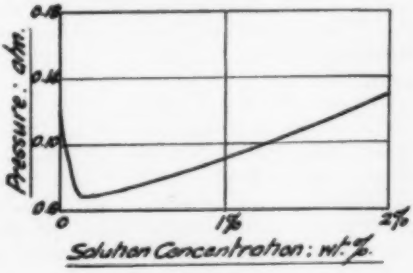


FIG. 6.

SOLUTION CONCENTRATION–PRESSURE CURVE OF KAOLIN MIXTURE OF FIG. 5.

In Fig. 5 the results of a complete series of tests with one chemical are given. They are plotted with the pressures as ordinate and the instrument revolutions per minute as abscissa. The flow characteristic is seen to vary

with the concentration of the sodium sulphate, but the change is not directly proportional to that concentration. From the initial viscosity, that of a kaolin-distilled water mixture, a decrease occurs, and then, after a minimum is reached, the fluid becomes more viscous. This, of course, is a phenomenon which has been constantly observed, but where a fluid which possesses the capacity to gel is under test it is a matter of extreme difficulty accurately to determine the minimum point with such certainty.

Converting to centistokes the pressures recorded with the instrument running at a speed of 100 r.p.m. and plotting them on a graph of which the ordinate is viscosity and the abscissa is concentration of the chemical, Fig. 6 shows clearly the change of flow characteristic with changing concentration. Figs. 7*a* to 7*g* are such curves for the seven chemicals quoted above, and it will be seen that each has its particular and distinct properties. For these particular kaolin–water mixtures the minimum viscosity is attained at concentrations given below:

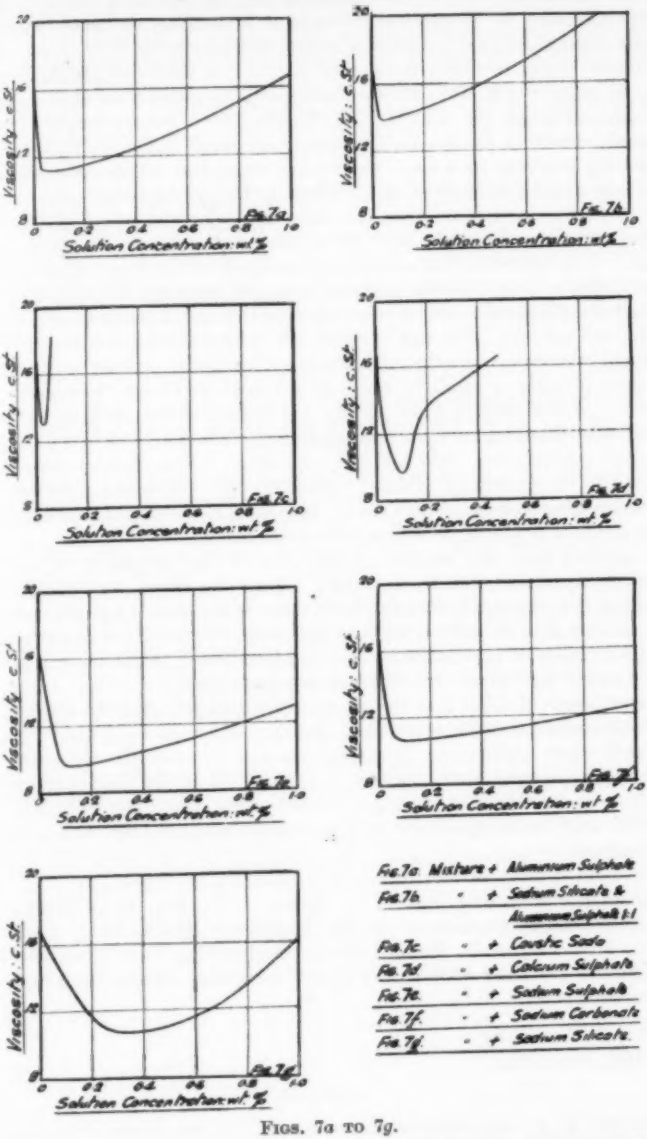
(I) with aluminium sulphate, caustic soda and the mixture of aluminium sulphate and sodium silicate at about 0·025 per cent.
(II) with calcium sulphate and sodium sulphate at about 0·10 per cent.
(III) with sodium carbonate at about 0·25 per cent.
(IV) with sodium silicate at about 0·35 per cent.

In cases (I) and (II) the minimum is plainly indicated, and is attained by the addition of a very small quantity of the respective chemical. An increase of the chemical percentage increases the viscosity until, very soon, a plastic state is reached. With a caustic soda content of 0·25 per cent. or an aluminium sulphate content of 2·0 per cent. the mixtures attained a very viscous condition. Where the mixture of aluminium sulphate and sodium silicate was used, the apparently almost plastic mass broke down completely under the influence of the agitation in the flow circuit. The mass has a thixotropic quality such that agitation of very small magnitude will convert the intense gel condition into that of a sol.

The mixtures containing sodium sulphate or calcium sulphate formed unstable gels which were easily broken. A comparison of the slope of the r.p.m.–pressure curves of these two mixtures between 1 and 20 r.p.m. with that of aluminium sulphate curves at the same speeds shows that the latter have steeper inclinations. From this one can deduce that a stronger capacity to gel exists.

In the case of (III) and (IV) the effects are not the same, although the minimum viscosity occurs at about the same point. When sodium silicate is added, a mixture is obtained which is a homogeneous and compact mass, the velocity of the gel building being rapid. With the addition of 0·1 per cent. of sodium carbonate, the mixtures, even after standing for 48 hours, are light flocculent masses. Consequently in the concentration–viscosity curve the minimum is very ill-defined—in other words, an addition of more than 0·1 per cent. of the chemical exercises little influence on the viscosity. On the contrary, the addition of an extremely small percentage amount of caustic soda gives rise to a viscosity change which may be described as violent.

It may be mentioned here that extended tests were conducted with mixtures of known *p*H values, and in the majority of cases no direct or even


Viscosity: c.St.
Solution Concentration: wt %
Fig. 7a
Fig. 7b
Fig. 7c
Fig. 7d
Fig. 7e
Fig. 7f
Fig. 7g
Fig. 7a Mixture + Aluminium Sulphate
Fig. 7b " + Sodium Silicate & Aluminium Sulphate 1:1
Fig. 7c " + Caustic Soda
Fig. 7d " + Calcium Sulphate
Fig. 7e " + Sodium Sulphate
Fig. 7f " + Sodium Carbonate
Fig. 7g " + Sodium Silicate

FIGS. 7a TO 7g.

SOLUTION CONCENTRATION–VISCOSITY CURVES FOR CHEMICALLY-DOCTORED KAOLIN–WATER MIXTURES.

general connection between this function and the viscosity could be determined. In fact, on theoretical grounds, it is not easy to detect why such a connection should exist except in some particular cases.[30, 31]

Further, these results fail to show agreement with the Hardy–Schulze law—in other words, it is by no means safe to predict on that basis the probable effect of the addition of chemical to a rotary mud. This is, naturally, entirely due to the extremely involved chemical and physical conditions inherent in a clay–water mixture, a fact which renders all the more important a method of rapid determination of viscosity variations.

It must be emphasized that the tests involving the effect of doctoring on the mixtures detailed above were conducted with kaolin as the solid phase. This material was chosen on account of its even graduation of particle size. Its relatively uniform chemical constituents rendered more uniform the effects of selective adsorption of the added electrolyte or colloid, as the case may be. On this account the chemical, physical and physico-chemical reactions were by no means as variable as they would be in ordinary practice, especially when it is considered that the quality and quantity of the drilling fluid are by the nature of the drilling operation continually changing, not only as regards particle size, but also as regards chemical constituents. Occasionally, however, circumstances arise which necessitate the sealing of strata (" mudding off "), or where a drilling fluid is not changing at a rapid rate, and it is in such cases that the investigation of the effect of doctoring is well worth undertaking.

It appears that any results obtained by the investigation of apparent viscosity variations due to doctoring cannot be taken as general. One arrives at the constantly stressed fact that " every well is a study in itself." The various factors influencing the apparent viscosity are capable of an infinite number of permutations and combinations; problems can only be solved on the field for each individual case as it arises.

Nevertheless, it is felt that the information gained during the course of the above described investigation may indicate the reactions which may be expected when adding the chemicals mentioned, and that the method of determining comparative apparent viscosities where the flow characteristic variation is quickly and visibly recorded, even where the fluid has a gel stability such as to approach an appearance of plasticity, has a definite practical use.

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Masjid-i-Sulaiman,
10th June 1935.

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REPORT ON THE INTERNATIONAL ELECTROTECHNICAL COMMISSION HELD AT THE HAGUE, JUNE 18–21, 1935.

By E. A. Evans, F.C.S. (Member).*

At the International Electrotechnical Commission, Strasbourg, it was agreed to investigate to what extent in B.S.I. Class "A" Transformer Oil the "ageing" is attributable to factors other than those operating in the transformer. The indications are that the Michie Sludge Test places the oil in an enhanced position. Continental users apply other tests which appear to indicate that oils with a higher sludge value are preferable in use.

The subject had previously been discussed at the I.E.C. at Stockholm in 1930.

Accordingly, it had been agreed that Pennsylvanian, Texan, Venezuelan and Russian oils of suitable viscosity should be refined into three grades :—

(*a*) weakly-refined,
(*b*) moderately-refined,
(*c*) highly (over) refined.

The moderately-refined oil would be approximately equivalent to the A.S.E.A. (Sweden) Specification, and the highly-refined oil would be equivalent to the B.S.I. Class "A" Transformer Oil.

At the meeting at The Hague Mr. Andersen (A.S.E.A. Sweden) presented a very comprehensive report dealing with the chemical aspect of the subject and the results he had obtained on experimental transformers. His researches had been confined to the Venezuelan oils. His results showed that with oil of this origin the moderately-refined oil gave much better results than the highly-refined. The work was very comprehensive, and must have involved much time and money. Unfortunately, there was no other report of a similar nature dealing with oils of other origins, so that no comparison was possible. Further, it was a pity that there was not more information available on the refining methods. It did seem to be clear, however, that the moderately- and highly-refined oils were both subjected to SO_2 treatment and had then been washed with sulphuric acid. Obviously, to produce the highly-refined a much larger amount of sulphuric acid had been used. True, the highly-refined oil had been produced to meet a particular sludge value, but we are not told what quantity of material was removed from the oil to obtain this result. Presumably it was quite considerable. We are left with the uncertainty as to whether oils from other origins would have given more favourable results than those found by Mr. Andersen.

According to Andersen's findings, the amount of soluble sludge pro-

* Representative of the Institution of Petroleum Technologists on the International Electrotechnical Commission.

duced in the transformer when using the moderately-refined and the highly-refined oils were equal at twelve months' service, but after this stage there was much more soluble sludge produced from the highly-refined oil than from the moderately-refined oil, the soluble sludge being apparently the forerunner of the insoluble sludge. It would be estimated by its insolubility in petroleum spirit. In the case of the insoluble sludge it was higher with the highly-refined oil than with the moderately-refined oil after twenty-four months.

The production of acid is approximately the same with the three oils up to about ten months. After this period the generation of acid in the highly-refined oil is greater than in the other two grades of oil.

In England there has been a good deal of discussion in defence of the highly-refined oil, but most of the observations have probably been derived from laboratory considerations, whereas Andersen has based his observations on research transformers. The criticisms may well be that three or four research transformers will not necessarily indicate what would happen in many transformers. That is a difficulty which will arise with any type of research. A further criticism is that the work was based on Venezuelan oil alone. Whatever the criticism, Andersen's work is of considerable value.

According to the A.S.E.A. method of test, highly-refined oil shows worse than the medium-refined oil. It is worthy of note that the results obtained by this method do compare favourably with the results on the research transformers. Andersen said that it is not an expensive test, nor is it difficult to carry out, although very high voltages are used in conjunction with the test. Exactly what the function of the electric field is may be open to some discussion, but no doubt it was put in originally to imitate the conditions in the transformer, though it may be a little difficult to accept this when one considers the design and electrical conditions in a working transformer. It may be that the electric field does exert an influence. Dr. Evers (Germany) exposed oil to a high electric field (18,000 volts), and he found that the iodine value increased from 2 to 100, although the experiment was made in a vacuum at 60° C. It is significant that this change should occur in the absence of oxygen. It is also interesting to note that hydrogen was evolved during the reaction. It is, of course, possible that there was dissolved oxygen in the oil which was converted to ozone by the electric field and this was immediately absorbed. Andersen, on the other hand, is satisfied that no ozone is produced by the electric field in his apparatus. Further, he suggests that the oxygen absorption is the same with and without the electric field. It would appear, therefore, that the electric field assists in the polymerization of the hydrocarbons, and subsequently in the production of sludge. The practical application of this suggestion is that most sludge forms on the most stressed part of the windings. Andersen recorded that much of the sludge produced in the test forms on one of the electrodes. Dr. Weiss (Strasbourg) suggests that sludge separates on the windings of the transformer and on the cylinder in the Andersen test due to electrostatic attraction. Dr. Bruckmann (Delft) has shown that sludge can be repelled from the centre pole of a condenser and attracted on to the guard ring surrounding it.

Weiss reviewed a variety of tests to see whether any of them can be applied with greater usefulness to the differentiation of transformer oils. He placed some reliance on the differences observed in the distillation curves of different oils indicating that the oils are different in constitution. He evoked some discussion on oxygen absorption, but it is possible that he may not have fully realized that there is an equilibrium between the oxygen available and the oxygen absorbed. Unfortunately, a great deal of work which has been published on oxygen absorption has not taken full account of this fact. There was a faint hope that an oxygen absorption method might be introduced as an international test to replace the Michie Sludge Test and tests based on similar principles.

In the past there has been much argument in support of the fitment of a condenser to the sludging apparatus, but it has now been realized that volatile compounds are only slowly produced in the transformer, and can, therefore, escape through the breather. If this be so, it matters little whether the volatile compounds do assist in the production of sludge if they are lost by evaporation before they have time to enter into some chemical reaction.

Weiss reminded the meeting that oil absorbs more oxygen than water, and that this absorption is much more pronounced in light than in darkness. It is important, therefore, that samples for test should be kept both in the absence of air and light.

Weiss strongly advocated the inclusion of a saponification value, particularly for oils which had been used, on the ground that products which are saponifiable will give rise to electric losses in the transformer. Evers undertook to do some work on the electric losses by the method described by Professor Keimath (Germany). So far there seems to be little knowledge on electric losses due to the oil in the transformer.

The Continental chemists feel, and the opinion is probably shared by the British chemists, that 150° C. may be too high a temperature to study the behaviour of oils for use in transformers. This being so, it is necessary to reduce the time of the test which would be automatically inevitable through a reduction in the temperature. If air is to be the oxidizing medium, then the volume of air must be increased, with the attendant risk of higher evaporation loss during the test. The alternative is to use oxygen. Certain British chemists have opposed the use of oxygen, but it is very clear that the subject is worthy of further consideration, and it was agreed to devote some attention to it. It was also agreed that the volatile products of decomposition should receive some further consideration.

Eriksson (Sweden) asked whether it pays to use the B.S.I. Class "A" Oil. He was inclined to think that even in England this oil was losing prestige. He suggested that the Insulating Oil Committee should work in co-operation with the Committee on Transformers and the Committee on Cables. It should first be determined whether there are any real troubles to be found in transformers due to the oil. If everybody was satisfied, there is no problem, but until the various interests are harnessed, we can only guess at the real problems. There is just a possibility that someone may find he is using an unnecessarily high grade of oil and may think he is spending too much on it. He will then suddenly decide on a lower grade

for economic reasons. It is the job of the research organizations to discover these facts first, and for the industrial organizations to lay their plans on the results of the researches.

The investigations will continue, but the research workers do ask for a greater measure of sympathy, because the firms with whom they are associated have spent large sums of money on the investigations, and the delegates who meet together from various countries were now viewing the problems with much more unity, and there was every hope that the obscurities would be revealed.

The British delegates left the meeting feeling that the case for the B.S.I. Class "A" Oil was less strong and that the reasons for it were slowly becoming revealed. It was not suggested that B.S.I. Class "B" Oil was the proper thing, but rather an oil intermediate between "A" and "B."

Whether we are nearer to an international method of test is very difficult to say, but it is clear that the I.E.C. is performing a useful work in bringing together the various nationals to ventilate their views and problems.

CORRESPONDENCE

To The Editor.

Sir,—In my article on "Lubricants and Lubrication" (Reports on the Progress of Naphthology, 1934) I refer to the work of Godlewicz and Pilat * on the fractionation of petroleum by means of hydrocarbon gases dissolved under pressure. I mention the fact that the work is based upon, and appositely refers to, the Polish patent of the Institute for Chemical Research of as far back as 1920, describing the use for fractionating purposes of hydrocarbons boiling below room temperature.

In a letter from Professor Pilat just received he informs me that the Polish patent 1029, which is identical with the German patent 362,458 issued in 1921, restricts the operation to the process of de-asphaltizing and does not mention the possibility of actual fractionation with gaseous solutions. The first attempts to fractionate with gas solutions at room temperatures or below were instituted by Professor Pilat and his colleague.

Yours faithfully,

S. J. M. Auld.

London, November 4th, 1935.

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* See p. 380.